DATE ISSUED JUL 27 1973

ORNL-4893

DYNAMICS OF LITTER DECOMPOSITION, MICROBIOTA POPULATIONS, AND NUTRIENT MOVEMENT FOLLOWING NITROGEN AND PHOSPHORUS ADDITIONS TO A DECIDUOUS FOREST STAND

James Michael Kelly

OAK RIDGE NATIONAL LABORATORY
OPERATED BY UNION CARBIDE CORPORATION • FOR THE U.S. ATOMIC ENERGY COMMISSION

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22151
Price: Printed Copy $7.60; Microfiche $0.95

ORNL-4893
UC-48 — Biology and Medicine

Contract No. W-7405-eng-26

Environmental Sciences Division

DYNAMICS OF LITTER DECOMPOSITION, MICROBIOTA POPULATIONS, AND NUTRIENT MOVEMENT FOLLOWING NITROGEN AND PHOSPHORUS ADDITIONS TO A DECIDUOUS FOREST STAND

James Michael Kelly

Submitted as a dissertation by James Michael Kelly to the Graduate Council of the University of Tennessee in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

JULY 1973

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ACKNOWLEDGMENTS

I express my gratitude to Drs. J. W. Curlin, W. A. Thomas, and E. E. C. Clebsch for directing and criticizing the research, and to Dr. G. S. Henderson for his most valuable assistance and advice during the preparation of the manuscript. I thank also Drs. G. M. Lessman, C. C. Amundsen, D. E. Reichle, W. F. Harris, and M. Witkamp for their suggestions and critical reading of this manuscript. I also express my appreciation to Mr. W. J. Selvidge, Mr. A. E. Hunley, and Ms. Marion Ferguson for their assistance with the chemical determinations and to Dr. J. J. Beauchamp for his assistance with the statistical analyses.

This research was conducted at the Environmental Sciences Division of Oak Ridge National Laboratory and was supported by the Oak Ridge Graduate Fellowship Program of Oak Ridge Associated Universities. Oak Ridge National Laboratory is operated by the Union Carbide Corporation for the U. S. Atomic Energy Commission.

ABSTRACT

The objective of this study was quantification of the dynamics of litter decomposition, microbiota populations, and nutrient movement in response to nitrogen and phosphorus additions to a deciduous forest stand. Nitrogen (urea) was applied at rates of 0, 550, and 1100 kg/ha in combination with phosphorus (concentrated superphosphate) at rates of 0, 275, and 550 kg/ha.

Total loss of organic material from white oak, red maple, and black gum litter bags over a 16-month period was 34, 35, and 45%, respectively. Phosphorus treatment retarded weight loss from litter bags of all species. Weight loss for the 0-, 275-, and 550-kg/ha levels of phosphorus averaged 23, 20, and 19% for white oak; 26, 25, and 25% for red maple; 29, 27, and 26% for black gum. Weight losses were increased by a small amount (1 to 2%) or not at all by nitrogen treatment. The NP interaction weight loss means were intermediate to the main treatment means. The increase in decomposition associated with nitrogen was offset by the decrease associated with phosphorus.

Litter and soil bacterial populations were significantly increased by nitrogen additions, while litter and soil fungi did not respond to nitrogen. Soil fungal populations were increased by phosphorus addition, while litter bacterial populations were reduced. Litter fungi and soil bacteria did not respond to phosphorus. Combined additions of nitrogen and phosphorus increased bacterial populations, though not as much as nitrogen alone. There was a good correlation (r = 0.70) between bacterial population and litter weight loss.

Invertebrate populations in white oak and red maple litter were reduced by nitrogen treatment; however, phosphorus treatment increased only the red maple invertebrate population. Invertebrates inhabiting black gum litter were not affected by fertilization. The change in invertebrate population appears to be in response to pH changes following fertilization. The shifts in invertebrate populations did not correlate with weight loss as well as the shifts in microbial populations did ($r = 0.35$).

The nitrogen content of the litter exhibited the same response pattern regardless of fertilizer treatment, although there were differences in the magnitudes of the responses. The dynamics of nitrogen in the litter correlated well with microbial population ($r = 0.85$), while nitrogen loss from the litter and top 10 cm of the soil via the soil solution appeared to be controlled by chemical rather than biological factors. The formation of insoluble calcium ammonium phosphate was the primary chemical regulator. Significantly less nitrogen was lost at the 550-kg/ha level of phosphorus in combination with nitrogen than at the 275-kg/ha level. Phosphorus and calcium losses in the soil solution support the calcium ammonium phosphate fixation hypothesis. Solubilized organic matter was estimated as contributing 25 g/m^2 of nitrogen loss. Volatilization losses were estimated to be as high as 26 g/m^2.

Nitrogen treatment increased the amount of potassium, calcium, magnesium, and sodium in white oak litter, while phosphorus content was not altered. Phosphorus treatment increased the weight of phosphorus, calcium, and sodium, while reducing the weight of magnesium.

Potassium content was not affected by phosphorus treatment. The alteration of microfloral populations by fertilization was the primary factor controlling nutrient dynamics in the decomposing litter.

Nitrogen treatment significantly increased nitrogen and potassium losses from the litter and top 10 cm of the mineral soil via the soil solution. Phosphorus and calcium losses were reduced by nitrogen treatment, while sodium and magnesium losses were unaltered. Phosphorus treatment increased the loss of all elements except nitrogen.

TABLE OF CONTENTS

CHAPTER PAGE

LIST OF TABLES

TABLE PAGE

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

FIGURE PAGE

FIGURE PAGE

CHAPTER I

INTRODUCTION

The prospect of turning waste land into useful timber production and improving the growth of existing forest stands on average or better sites through the use of chemical fertilizers is attractive. The increasing demands placed on our slowly renewable forest resources for lumber and other wood products, coupled with an ever decreasing forest acreage, increases the economic feasibility of full-scale forest fertilization (Mustanoja and Leaf 1965).

Forest management in the past was largely confined through various methods and practices, to the conservation of the natural fertility of the forest through the preservation of the organic detritus on the forest floor (White and Leaf 1956). The large-scale use of such practices as clear-cutting and whole-tree logging will generally degrade the natural fertility level and thus necessitate the addition of fertilizers to maintain site quality (Tamm 1969). While an increase in forest productivity through the enrichment of natural nutrient pools with chemical fertilizers is desirable, certain other aspects of forest fertilization relating to the total environment should be evaluated prior to massive fertilization programs. Forest fertilization needs to be evaluated in terms of total environmental impact so that recommendations can be made about time of fertilization; fertilizer types, levels, and combinations; and the suitability of a particular site for the application of fertilizer.

A generalization from the agronomic and horticultural literature is that the addition of chemical fertilizers, especially nitrogen, increases the breakdown rate of fresh organic detritus. If this holds true for fresh forest litter, then the addition of chemical fertilizers could stimulate mineralization thereby releasing over a relatively short period of time those nutrients that would normally be released over a more extended period. This release of nutrients from the litter could occur under less than optimum conditions for uptake and lead to loss from the feeder root zone.

This study had two principal objectives: (1) to evaluate the short-term effect of the addition of various levels and combinations of nitrogen and phosphorus on the decomposition and nutrient dynamics of leaves representative of species which would be found in the O_1 component of the litter compartment of an oak-hickory forest and (2) to evaluate the effect of this perturbation on the nutrient status of the soil solution. A secondary objective was to evaluate the effect of fertilizers on the population levels of microflora and microfauna associated with the decomposition process. This investigation was conducted in conjunction with the Walker Branch Watershed Project of Oak Ridge National Laboratory, an integrated research project designed to study biogeochemical cycles in the forested landscape.

This study was designed to provide information on decomposition from both a natural and a fertilized system. Information gained from the unfertilized plots will serve as baseline characterizations of the nutrient status of the soil solution and provide additional quantification of the mineral status of decomposing leaves. Information derived from the fertilized plots will provide insights into short-term effects of fertilizers on the litter compartment and the soil solution. An understanding of mineral cycle dynamics under both natural and perturbed regimes is required in order to have sufficient scientific basis to assist in providing solutions to problems of ecosystem management.

CHAPTER II

EXPERIMENTAL AREA

Location

Study plots were established on Walker Branch Watershed, which is located within the U. S. Atomic Energy Commission Oak Ridge Reservation in Anderson County, Tennessee. The 97.5-ha watershed lies within the Ridge and Valley Physiographic Province (McMaster and Waller 1965). The catchment is bounded on the north by Chestnut Ridge which reaches an elevation of 345 meters and slopes rapidly southward to an elevation of 250 meters in the valley bottom (Curlin and Nelson 1968).

Climate

The climate of Anderson County is of the humid mesothermal type, with moderate summer and winter temperatures (Holland 1953). The frost-free period extends from mid-April to late October, averaging 196 days (Holland 1953). The mean annual precipitation is 135 cm and is well distributed through the year. Precipitation generally occurs as gentle showers lasting for half a day or more with heavy thunder showers occurring during the summer months.

Mean monthly temperatures during the study period were below the long-term mean during the first nine months of the study and above the long-term mean during the final eight months of the study (Figure 1). The frost-free period of 1971 lasted from April 6 to November 8, a total of 218 days. Freezing temperatures were still occurring when the study was terminated in March 1972. Total precipitation during the 16

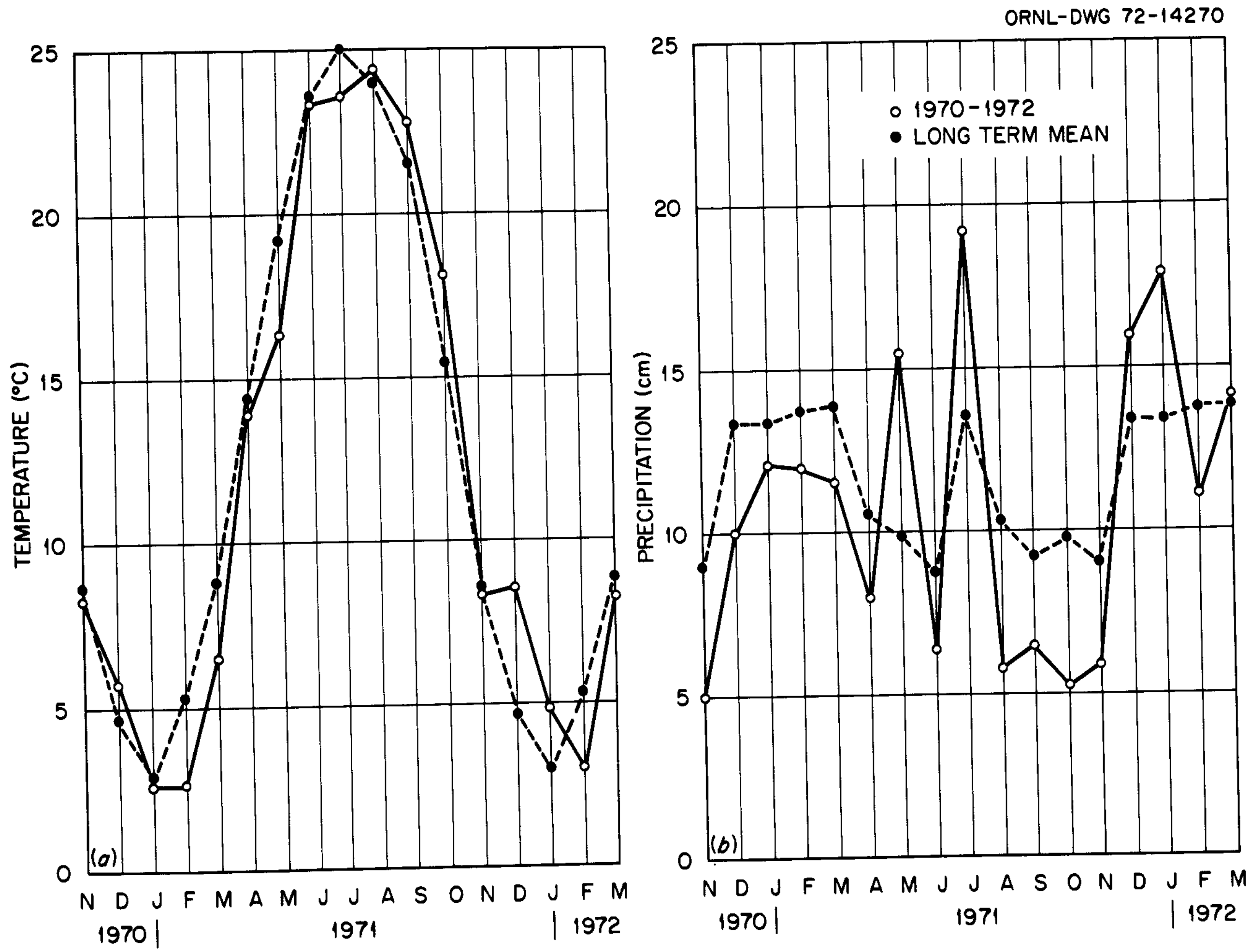

Figure 1. Long-term monthly temperature (a) and precipitation (b) means based on local climatological data collected by the Oak Ridge Weather Service Office of the National Oceanic and Atmospheric Administration, and the temperature and precipitation monthly means for the period November 1970 through March 1972.

months of the study was 180 cm, compared to 197 cm on a long-term basis. Heavy showers of long duration were common in July, December, and January. Precipitation in the form of ice and snow was negligible.

Geology and Soils

The watershed is underlain by Knox Dolomite, a siliceous, medium to light grey, dense to coarsely crystalline dolomite rock of late Cambrian to early Ordovician age. Jasper chert is found in abundance in the upper 12 meters of the regolith (Curlin and Nelson 1968). The soils are primarily Typic Paleudults. These soils are generally well drained and have a high infiltration capacity. The predominant clay mineral is kaolinite, with lesser amounts of vermiculite, hydrous micas, and quartz forming the complement. The study site was on a ridge top dominated by Fullerton cherty silt loam. Fullerton soils have brown cherty silt loam A horizons and red cherty clayey B horizons. Depth to bedrock ranges from 2 to 14 meters. Chert content by volume of each horizon ranges from 15 to 35% in most pedons, with most chert fragments from 2 to 10 cm across. The entire profile is strongly acid with a pH range from 5.0 in the A_1 to 3.9 in the lower B_2. The clay content increases gradually from 20 to 30% in the B_1 to 35 to 60% in the B_2. The cation exchange capacity of the A_1 averages 3.30 meq per 100 g of soil, with a base saturation of 16% (Peters _et al_. 1970).

Vegetation and Flora

The Oak Ridge area is in the ridge and valley section, oak-chestnut part of the eastern deciduous forest (Braun 1950). The overstory vegetation of Walker Branch Watershed is predominately an oak-hickory association (59%) with lesser amounts of mesophytic hardwoods (24%), pine (11%), and pine-oak-hickory (3%) (Curlin and Nelson 1968). Chestnut oak (*Quercus prinus* L.) was the predominant species in the study area contributing 24% of the total stems greater than 2.5 cm. White oak (*Quercus alba* L.) contributed 17%, black gum (*Nyssa sylvatica* Marsh) 16%, and red maple (*Acer rubrum* L.) 13%. The remaining 30% was contributed by several minor species; the most common species were black oak (*Quercus velutina* Lam.) and sourwood (*Oxydendrum arboreum* L.). Dogwood (*Cornus florida* L.) was the principal understory species. Seedlings of understory and overstory species along with spotted wintergreen (*Chimaphila maculata* L.) and Japanese honeysuckle (*Lonicera japonica* Thunb.) comprise the majority of the forest floor species. Prior to acquisition by the United States Government in 1942 the study area had been relatively open land and was used periodically for woodland pasture and selective timber production (Auerbach 1972).

CHAPTER III

MATERIALS AND METHODS

Treatment Plots

The study area is approximately one-half hectare in area and has an average elevation of 330 meters and a slope of 12%. The experimental site located in an oak-hickory stand was divided into three blocks, each of which contained nine treatment plots. Each treatment plot was 4 by 6 meters with the long axis oriented down slope. The plots were laid out in a three plot by three plot block with a one-meter border strip surrounding each plot.

Fertilizer Treatments

Fertilizer-grade urea [$CO(NH_2)_2$] with an elemental nitrogen content of 45% was used as the nitrogen source. Concentrated superphosphate [$Ca(H_2PO_4)_2$] with an elemental phosphorus content of 19% was used as the phosphorus source. Three levels of nitrogen and phosphorus were combined in all possible combinations, resulting in a total of nine different fertilizer treatments. The treatments were as follows: (Nitrogen/Phosphorus) 0/0, 0/275, 0/550, 550/0, 1100/0, 275/550, 275/1100, 550/550, and 550/1100 kg/ha. The fertilizer was broadcasted on March 16, 1971, about four months after placement of litter bags.

Litter Bags

Freshly deposited white oak, red maple, and black gum leaves were gathered from the forest floor in the fall of 1970. These leaves were air dried to a constant weight and then placed in 30-cm by 30-cm nylon net bags. Each species was bagged separately with 7 g of air-dried leaf material being placed in each bag. On each plot, 52 white oak, 12 red maple, and 12 black gum litter bags were placed on the surface of the existing O_1 layer and secured with a color-coded 20-d nail. The photographs in Figure 2 present three views of the study area immediately after the litter bags were distributed. Leaf fall was approximately 50 to 60 percent completed at the time the bags were put in place (November 9, 1970).

Tension Lysimeters

Tension lysimeters of the type described by Cole (1958) were installed in each treatment plot of blocks one and two. The type of lysimeter used in this study was a 1-cm-thick by 28-cm-diameter alundum plate to the back of which a lucite chamber was attached with epoxy cement. A polyvinylchloride tube ran from the collection chamber to a 6-liter polyethylene bottle (Figure 3). The collection bottle was housed in a length of pipe 20 cm by 120 cm which had been inserted into the soil to a depth of 100 cm. The exposed end of the pipe was covered by a plastic cap.

Prior to installation the plates were soaked in a 25% hydrochloric acid solution to charge the plate with water and saturate any exchange sites with hydrogen ions. The lysimeter plate was placed 10 cm beneath the surface of the mineral soil. Figure 4 illustrates the steps taken in the lysimeter installation procedure. Cutting the soil block on only three sides allowed the root system to remain relatively intact and promoted the healing of the cut area so that within one to two months the root network was reestablished. The lysimeter was

PHOTO 0041-73

Figure 2. General view of one block in the study area immediately after the litter bags were distributed (a), a single plot within that block illustrating the arrangement of the litter bags within a plot (b), and an individual litter bag and the surrounding O_1 litter (c).

ORNL-DWG 72-6157

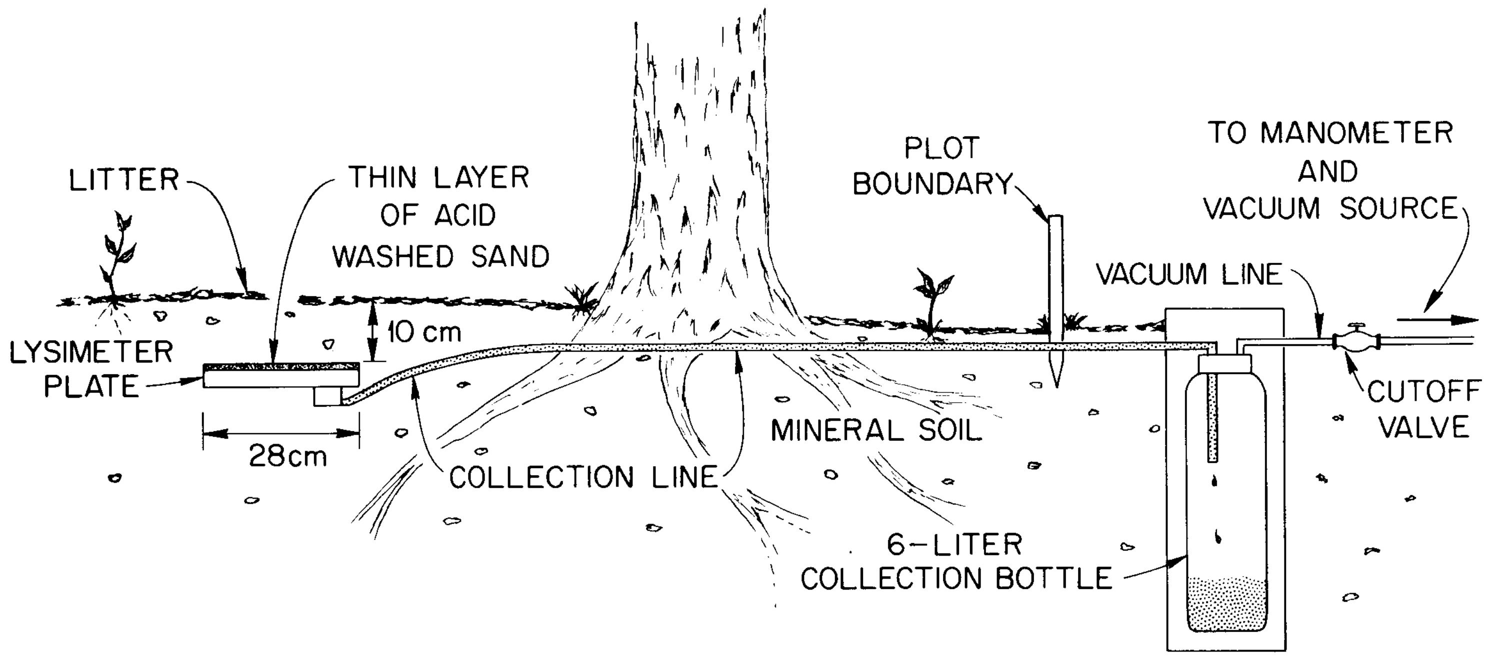

Figure 3. Cross sectional drawing of a plot illustrating the relative position of the lysimeter plate and the collection bottle.

PHOTO 0042-73

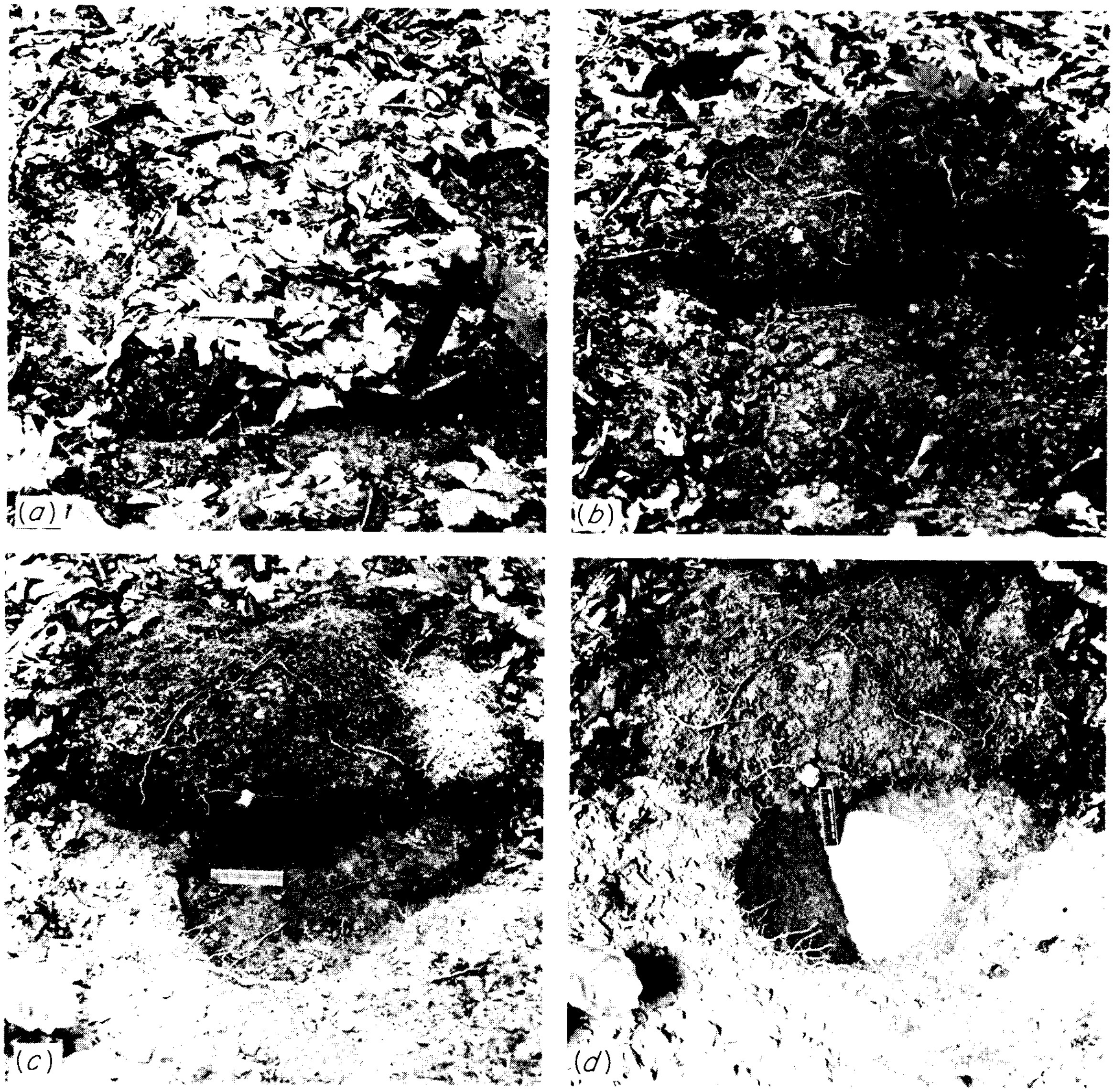

Figure 4. Steps taken in the installation of a tension lysimeter. A U-shaped cut to a depth of 10 cm was made in the soil (a). The soil was folded back (b) and a small pit was dug to accommodate the lysimeter plate (c). A 0.5 cm layer of fine acid washed sand was placed on the surface of the plate (d), and the soil block returned to its original position.

covered with fine acid washed sand in order to insure continuous contact between the overlying soil and the surface of the lysimeter plate. The soil block was folded back in place, and the edges of the cut were sealed with soil removed from the hole. Five liters of water was applied to the surface of the litter to settle the soil and to check the contact of the lysimeter plate and soil. Vacuum for the lysimeter plates was supplied by an automatic vacuum pump system set to maintain a constant tension of 1/10 bar at the plate surface. This tension was approximately equal to the matric potential of the soil.

Sampling Procedure

All aspects of the sampling procedure in both the field and laboratory are summarized in Figure 5. Since most of the procedures used in this study are standard techniques, only the pertinent details will be elaborated.

Water. Samples of the soil solution were collected at 7-day intervals during periods of favorable soil moisture. Approximately 0.5 cm of precipitation within a 24-hr period was necessary to obtain a collection during the dormant season, and 1 cm or more was necessary during the growing season. Water samples were returned to the laboratory and the soil solution pH was determined with a Beckman pH meter equipped with Corning glass electrodes. Two 25-ml aliquots were used for ammonium and total nitrogen determinations. The remainder of the sample was filtered through Whatman No. 1 filter paper. Light transmission through a 5-ml aliquot of filtered solution was measured on a Beckman

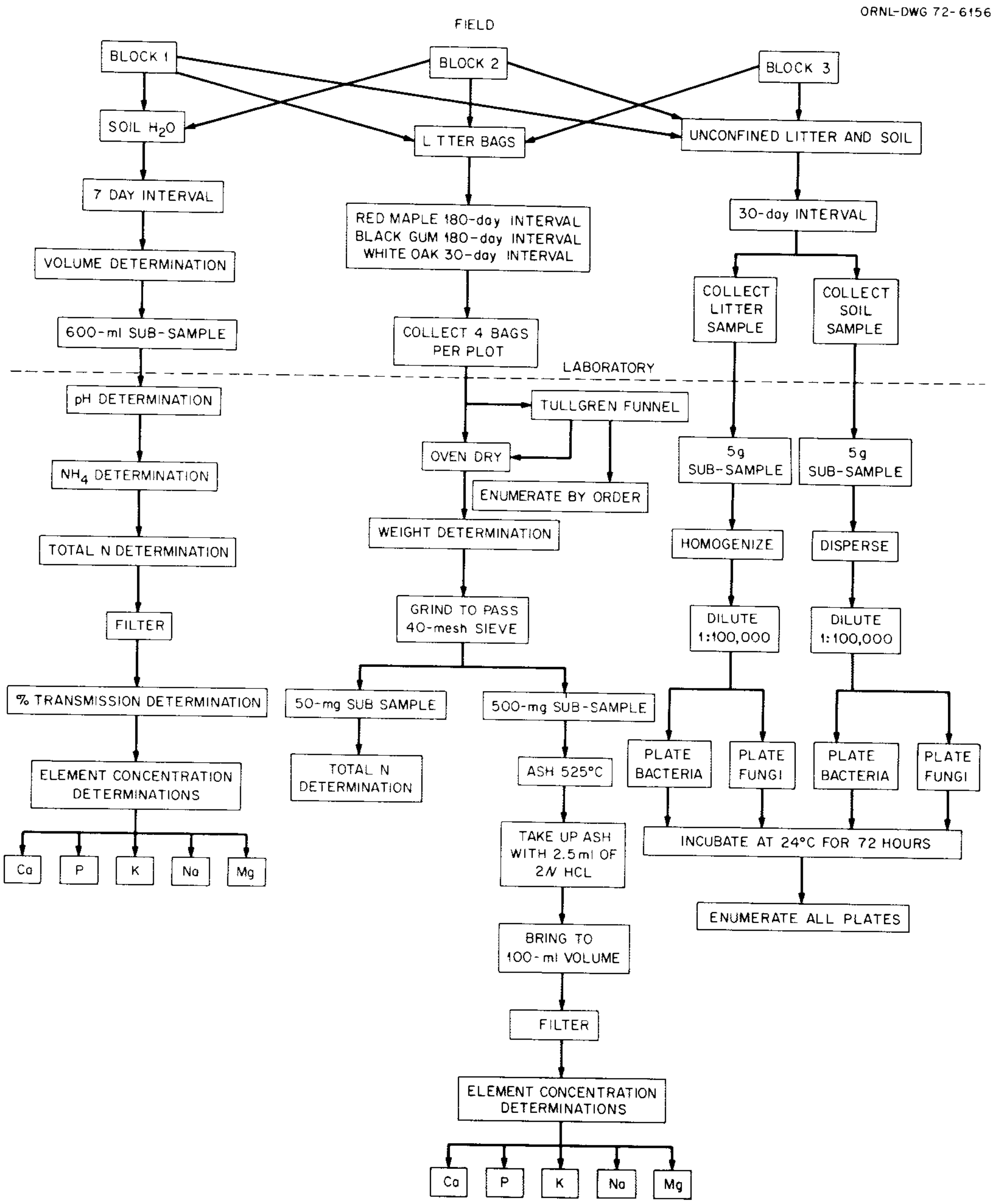

Figure 5. Block diagram of field and laboratory procedures.

D. U. Spectrophotometer set at a wavelength of 410 microns. This procedure was adopted to quantify the turbidity of the soil solution following fertilizer treatment. One milliliter of 1 N HCl and 0.1 g of mercuric chloride were added to each sample as preservatives. A 20-ml aliquot was taken prior to the addition of mercuric chloride since mercury ions interfered with the phosphorus determination method. The remainder of the sample was stored until calcium, potassium, sodium, and magnesium determinations could be made.

Litter bags. Four litter bags of each species were collected at either 30- or 180-day intervals from March 15, 1971, through March 10, 1972. The four bags were chosen at random and freed of any external organic or mineral soil contamination. One bag from each plot was put in a plastic bag and returned to the laboratory, where it was placed on a Tullgren funnel for the extraction of invertebrates. After the bags were oven dried at 105°C for 24 hr they were weighed to determine weight loss. Two of the four bags collected from each plot were chosen at random for chemical analysis.

Bacteria and fungi counts. Samples of unconfined O_1 and O_2 litter and soil were collected at 30-day intervals for use in determination of bacterial and fungal population levels. A composite sample of approximately 50 g was taken from the combined O_1 and O_2 layers of the litter horizon in each treatment plot. At the same point in each treatment plot where the combined O_1 and O_2 litter sample was collected, approximately 25 g of soil was collected. A sampling tube 1 cm in diameter was inserted into the soil four times to a depth of 10 cm, and all soil collected within a treatment plot was composited into a single sample.

Standard microbial dilution plate counts were used to characterize population levels of bacteria and fungi in both litter and soil (Waksman 1927). A 5-g (wet weight) subsample was taken from the sample collected on each treatment plot. The subsample was placed in 195 ml of sterile water and homogenized in a Vertis "45" tissue homogenizer for 10 sec at 800 rpm. A 1-ml aliquot from a 1:100,000 dilution was placed on nutrient agar for bacterial determination and on rose bengal agar for fungal determination. Turgitol was added to the nutrient agar to retard fungal growth. The plates were counted after incubation for 72 hr at 24°C.

To enumerate bacterial numbers, a 1-cm grid was placed beneath the plate and the number of bacteria within ten of the squares was counted. The same ten squares were used in all counts to avoid bias. A dry-weight conversion factor was determined for each sampling date so that total colonies per gram dry weight of litter could be determined. Fungal population levels were determined by directly counting all fungal colonies on an individual plate and then applying the appropriate conversion factor to convert the number to a per gram dry weight basis.

Bacterial and fungal counts for the soil were obtained by taking a 5-g (wet weight) subsample of soil from each treatment plot and placing it in a 45-ml sterile water blank. These soil and water samples were placed on a rotary shaker at 100 cycles per minute for 1 hr. One-milliliter aliquots from a 1:100,000 dilution were placed on nutrient agar and rose bengal agar and incubated for 72 hr at 24°C. The bacterial and fungal colony enumeration procedure used for soil was identical to that used for the litter.

Tullgren extractions. Litter micro- and macroinvertebrates were extracted from litter bags through the use of Tullgren funnels (Tullgren 1918). The bags were covered with a single layer of cheesecloth to prevent the extracted samples from becoming unduly cluttered with fine leaf particles and thus adding to the difficulty of enumeration (M. H. Shanks, personal communication). The bags were left on the funnels for 24 hr under the constant heat provided by a 40-watt light bulb. The organisms driven from the litter bag fell into a glass vial containing an alcohol solution and were preserved until they could be counted. Each sample was examined under a binocular microscope, and the organisms present were enumerated by taxonomic orders.

Chemical Analysis

Water. Immediately after collection, 25-ml aliquots of soil solution were analyzed for ammonium-N. The samples were placed in semi-micro Kjeldahl flasks and steam distilled into boric acid indicator solution (pH 5.0). The boric acid solution was back-titrated on a Beckman Automatic Buret Assembly coupled to a Beckman Automatic Endpoint Detector. An additional 25-ml aliquot of soil solution was taken for total nitrogen content determination. After digestion and distillation the boric acid indicator solution was back-titrated as for ammonium-N. Both the ammonium-N and total-N determinations for water samples followed the procedure outlined by Henderson (1972b).

Calcium, potassium, magnesium, and sodium determinations were made on a Perkin-Elmer Model 403 Atomic Absorption Spectrophotometer. The procedures used to determine each element are described in Kahn

(1971). Phosphorus determinations were made by the sulfuro-molybdate method on a Technicon Autoanalyzer. The details of the method used for the phosphorus determination are available in Lundgren (1960).

Leaves. After being oven-dried for 24 hr, the leaf samples were ground to pass through a 40-mesh sieve. Total nitrogen was determined by the semi-micro Kjeldahl procedure described by Black (1965). For elements other than nitrogen, a 500-mg sample of ground leaf material was placed in a porcelain crucible and ashed overnight at 525°C. The samples were allowed to cool and then the ash was taken up in 2.5 ml of 2 N HCl. After the ash samples were digested for 1 hr, they were washed from the crucibles into 100-ml volumetric flasks and brought to volume with distilled water. The samples were then filtered through Whatman No. 42 filter paper into a 200-ml polyethylene bottle containing two drops of 1 N HCl to prevent phosphorus sorption by the inner surface of the bottle. Concentrations of calcium, phosphorus, potassium, sodium, and magnesium in leaf material were determined by the same procedures outlined for soil water samples.

Data Handling and Statistical Analysis

The basic experimental design used in all components of the study was a randomized complete block with either one, two, or four subsamples per plot. The analysis of variance used was a 3^2 factorial using a fixed model. A modified version of the BMD 08V program written at the University of California at Los Angeles was used to perform the necessary analyses of variance. The SADS programs developed by Hume and Brooks (1970) were used to provide summary values (means) with a measure of variance. Tukey's "W" procedure (Steel and Torrie 1960) was used where indicated for the comparison of mean values. The 0.05 level of probability was used as the criterion for accepting or rejecting null hypotheses in all statistical analyses.

CHAPTER IV

RESULTS AND DISCUSSION

I. MICROFLORA

Serial dilution plate counts were used to determine population levels of bacteria and fungi. This method may reflect relative bacterial population density, although densities from direct counts are from 10 to 1000 times greater (Witkamp 1971b). Serial dilution counts of fungi are unlikely to reflect total fungal activity because certain groups are over represented, while others do not develop on the plates (Witkamp 1971). Nevertheless, plate counts can be indicative of microbial activity. Witkamp (1966) suggests that mean annual colony counts are more highly correlated with microbial activity than individual values taken through the course of a year. Effect of the various fertilizer treatments on bacterial and fungal populations of the litter and soil were evaluated by using mean annual colony counts.

Litter

The control mean for litter bacteria of 57×10^6 colonies per gram dry weight (Table 1) was within the range reported for deciduous litter in the literature. Variation among plots in population estimates was great, even before fertilizer treatment. This variability was due primarily to the heterogeneous distribution of bacteria and the sampling intensity employed.

Table 1. Temporal distribution of bacterial and fungal colonies per gram dry weight of litter substrate as a function of fertilizer treatment.

Date	Fertilizer Treatment Level (Nitrogen/Phosphorus)								
	0/0	0/275	0/550	550/0	1100/0	550/275	550/550	1100/275	1100/550
Bacteria ($x 10^6$)									
Nov. 1970	193[a]	103	87	124	107	108	86	111	96
Mar. 1971	113	168	132	100	130	61	139	84	57
Apr.	76	85	79	369	255	461	186	312	260
May	44	53	183	404	621	224	210	696	587
June	10	2	1	11	13	1	13	21	1
July	76	56	30	464	439	170	144	514	286
Aug.	66	53	27	483	415	179	158	599	282
Sept.	22	39	16	40	59	44	21	165	57
Oct.	60	10	10	58	134	83	32	84	67
Nov.	0	0	0	0	0	0	0	0	0
Jan. 1972	5	46	5	8	20	17	4	34	13
March.	17	6	6	8	42	20	5	29	45
$\bar{x}$	57	52	48	172	186	114	83	221	146
Fungi ($x 10^6$)									
Nov. 1970	6	4	2	3	3	2	2	4	2
Mar. 1971	1	1	< 1	1	1	1	1	1	1
Apr.	10	30	12	20	7	50	155	8	28
May	2	4	7	12	7	11	9	10	14
June	3	1	5	3	4	3	3	12	2
July	8	3	3	5	2	5	2	4	3
Aug.	9	4	3	6	4	6	2	9	4
Sept.	< 1	1	< 1	3	1	1	3	1	< 1
Oct.	10	6	2	7	7	10	4	10	8
Nov.	4	2	1	2	4	2	2	4	2
Jan. 1972	< 1	1	< 1	< 1	< 1	< 1	< 1	< 1	0
Mar.	0	< 1	1	3	2	1	1	1	< 1
$\bar{x}$	4	5	3	5	4	8	15	5	5

[a]Each value presented is the mean of three determinations, consequently, values less than one can occur.

Response of bacteria to phosphorus. Litter bacteria population means dropped from 139 x 10^6 colonies at the zero level of phosphorus to 129 x 10^6 and 93 x 10^6 colonies at the 275- and 550-kg/ha levels of phosphorus respectively; only the 550-kg/ha level was significantly lower. While the causal mechanism for this phenomenon is not entirely clear, two explanations are suggested: (1) the addition of phosphorus to the system at relatively high levels resulted in the complexing of available calcium ions into insoluble calcium ammonium phosphate compounds (Black 1957) which could reduce the general nutrient status of the litter and at the same time degrade the physical environment for bacteria by possibly lowering litter pH or (2) the reduction of bacteria level was due to the salt effect of the added fertilizer or to the formation of compounds that were toxic to bacteria. It is quite possible that the addition of phosphorus caused both of these phenomena to occur. This study cannot substantiate either of these postulates, although it has been documented that exchangeable calcium is necessary for bacterial growth (Witkamp 1966).

Response of bacteria to nitrogen. Mean bacterial level increased significantly from 53 x 10^6 to 124 and 185 x 10^6 colonies per gram in response to the increasing increments of the nitrogen main treatment. According to Witkamp (1966) the main factor controlling microbial density and activity is suitable substrate; a significant factor determining the suitability of a substrate is the carbon/nitrogen ratio. The addition of nitrogen fertilizer should, therefore, create a more suitable substrate for microbial activity by lowering the carbon/nitrogen ratio. The importance of available nitrogen and a favorable carbon/nitrogen ratio to microbial populations, especially bacterial, has been documented (Waksman and Tenney 1928; Allison and Klein 1961; Allison and Murphy 1962, 1963; Allison, Murphy, and Klein 1963; and McFee and Stone 1966). Comparison of the decomposition rates of several species suggests that the lower the carbon/nitrogen ratio, the higher the yearly weight loss (Witkamp 1964). A low carbon/nitrogen ratio does not necessarily indicate a high percentage of easily decomposable nitrogeneous substances. Olsen (1933), Caldwell and DeLong (1950), Bocock (1964) and others have documented increases in nitrogen in decomposing leaves. Such an increase might be due to the accumulation and retention of nitrogen in microorganisms (Witkamp 1963). While the carbon/nitrogen ratio is of considerable importance in controlling bacterial population, it is integrated with several other factors, all of which ultimately determine population level.

Response of fungi to fertilizer treatment. Fungal populations did not respond significantly to either the nitrogen or phosphorus main treatments nor was the nitrogen-phosphorus (NP) interaction significant (Table 1, p. 21). If the reduction of bacterial populations due to phosphorus treatment had been due to a pH shift, then the fungal population level should have increased, since lower pH favors the growth of fungi (Buckman and Brady 1969). The lack of a significant fungal response suggests that a reduced pH was not the mechanism responsible for the reduced bacterial level; however, the plate count method used to evaluate the fungal populations may have underestimated this parameter. The addition of nitrogen to the substrate probably gave the bacteria a competitive advantage, since bacteria are generally able to out compete fungi in the pH range of 6 to 8. If pH of the soil solution is indicative of litter pH, the litter pH appears to have remained in the range most conducive to bacterial growth. Litter pH may have risen as high as 10 immediately after fertilization in the urea-treated plots. This high pH level lasts only a few hours to a few days (Buckman and Brady 1969). Thus it appears that the litter bacteria competed successfully against the fungi for the added nitrogen.

Soil

Response of bacteria to nitrogen and phosphorus. Soil bacterial populations did not respond significantly to phosphorus fertilization (Table 2). Soil bacteria responded significantly to the nitrogen main treatment. The means for the 550- and 1100-kg/ha increments (89 and 93×10^6 colonies per gram respectively) were significantly different from the zero level mean (55×10^6), but not from each other. The addition of nitrogen also stimulated bacterial growth in the soil for the same reasons previously discussed in relation to litter bacteria.

Response of fungi to nitrogen and phosphorus. The soil fungi responded significantly to the phosphorus main treatment, but not to the nitrogen main treatment. The responses to the 0- and 550-kg/ha levels of phosphorus at 16 and 21×10^6 organisms per gram did not differ significantly, while the 275-kg/ha level (39×10^5) was significantly higher. A comparison of the annual means for the 0/275 and 0/550 treatments (Table 2) indicates that naturally occurring phosphorus may have been limiting, and the addition of 275 kg/ha was sufficient to stimulate

Table 2. Temporal distribution of bacterial and fungal colonies per gram dry weight of soil substrate as a function of fertilizer treatment.

Date	Fertilizer Treatment Level (Nitrogen/Phosphorus)								
	0/0	0/275	0/550	550/0	1100/0	550/275	550/550	1100/275	1100/550
Bacteria ($\times 10^6$)									
Nov. 1970	16	13	8	6	6	8	13	22	13
Mar. 1971	297	313	327	319	356	267	310	272	301
Apr.	23	44	30	159	228	106	366	255	130
May	11	8	11	78	274	152	29	73	114
June	0	1	1	0	107	1	1	0	4
July	158	6	10	87	51	31	20	62	110
Aug.	123	16	34	124	54	49	31	104	115
Sept.	27	21	14	192	9	61	67	104	123
Oct.	14	21	28	31	81	61	17	150	74
Nov.	0	0	0	0	0	0	0	0	0
Jan. 1972	6	166	197	34	14	260	16	56	35
Mar.	6	14	12	2	22	298	9	14	16
$\bar{x}$	57	52	56	86	100	108	73	93	86
Fungi ($\times 10^5$)									
Nov. 1970	2	9	4	3	13	5	9	6	6
Mar. 1971	12	26	2	11	3	16	14	16	2
Apr.	24	89	24	100	4	28	155	483	86
May	5	11	1	9	9	5	10	21	8
June	1	6	2	0	19	10	11	19	12
July	18	18	20	8	5	27	6	15	6
Aug.	25	31	33	6	6	39	25	24	16
Sept.	11	11	7	9	4	20	9	7	5
Oct.	4	9	16	18	7	49	7	4	11
Nov.	127	83	11	77	19	8	6	28	66
Jan. 1972	1	0	3	1	0	21	23	1	0
Mar.	0	5	5	3	4	5	0	0	12
$\bar{x}$	19	25	11	20	8	19	23	52	19

fungal growth, while 550 kg/ha was in excess of the required amount. The lack of a significant response to nitrogen would indicate that available nitrogen was not the factor limiting soil fungi. Due to a more favorable pH and the improved carbon/nitrogen ratio, the growth of the soil bacteria exceeded the soil fungi.

Response of fungi to the nitrogen-phosphorus interaction. The significant NP interaction was a result of the response mean for the 1100/275 treatment. This mean was the only one that was significantly different by a mean separation test. If the extremely high value of 483×10^5 colonies recorded in March 1971 (Table 2) is considered an artifact, then the exclusion of this value would bring the 1100/275 mean in line with the other treatments. Although the mean values for soil fungi are somewhat erratic, they indicate that the top 10 cm of the soil was able to mitigate the effect of added nitrogen and phosphorus more than the litter, and thus the effect of fertilization on both soil bacteria and fungi was not as great as the effect on litter bacterial and fungal populations.

II. MICROFAUNA

Soil invertebrates play both direct and indirect roles in the decomposition of organic matter. As a result of animal metabolism, complex organic substances and residues are reduced or fragmented to readily mineralized or plant available compounds (Kurcheva 1960). Without preliminary fragmentation by soil animals, many microorganisms cannot decompose the leaves of many species (Edwards et al. 1970). The importance of the microfauna in litter decomposition was shown by Witkamp and Crossley (1966), who found that a 36% reduction in the annual weight loss of white oak litter occurred when the invertebrate population was limited by chemical means. Bocock (1963), Parle (1963), and van der Drift and Witkamp (1959) have noted considerable changes in the chemistry of food substances during the passage through the digestive tract of invertebrate organisms. Witkamp (1960) has also found that the microfauna aid in the dissemination of nonmotile microfloral organisms.

White Oak

The microorganisms extracted from white oak litter bags on each of thirteen sampling dates belonged to the following taxonomic orders: Acarina, Collembola, Protura, Thysanura, Diptera, Hemiptera, Hymenoptera, Homoptera, and Coleoptera. The orders Acarina and Collembola dominated the microinvertebrate population. Only those two orders and the total population values were evaluated statistically for their response to fertilizer treatment. Phosphorus treatment did not alter total population or Acarina and Collembola populations.

Acarina and Collembola populations were not significantly altered by nitrogen treatment, but the total microfaunal population was reduced significantly by increasing the nitrogen level (Table 3). When the nitrogen level was increased from 0 to 550 and 1100 kg/ha, the response means dropped from 591 to 571 and 410 organisms per m^2. The lack of a significant NP interaction coupled with a significant reduction of total population by nitrogen indicates that the nitrogen main treatment

Table 3. Acarina, Collembola, and total invertebrate population levels in white oak leaf litter as a function of fertilizer treatment. Values presented represent the number of organisms per m^2 as determined by Tullgren extraction of white oak litter bags.

Date	Fertilizer Treatment Level (Nitrogen/Phosphorus)								
	0/0	0/275	0/550	550/0	1100/0	550/275	550/550	1100/275	1100/550
Acarina									
Mar. 1971	1030	600	290	840	150	910	320	40	180
Apr.	0	0	0	20	0	10	10	70	10
May	760	1410	130	240	220	440	580	1010	530
June	800	1200	410	750	540	310	610	650	750
July	450	510	350	340	430	218	320	540	460
Aug.	390	960	450	220	190	300	630	230	390
Sept.	440	300	470	270	290	170	380	320	370
Oct.	310	340	350	790	70	300	300	190	210
Nov.	550	350	430	280	110	210	280	170	230
Dec.	450	350	450	240	310	200	360	340	400
Jan. 1972	540	380	240	400	300	250	250	350	430
Feb.	1020	340	190	200	380	110	80	190	50
Mar.	140	50	80	210	30	70	70	240	430
Collembola									
Mar. 1971	320	60	90	90	110	130	120	150	90
Apr.	10	0	0	10	0	0	0	70	10
May	280	160	80	270	170	70	60	50	60
June	200	110	160	250	130	270	140	200	90
July	130	180	140	170	210	160	170	120	120
Aug.	140	200	160	110	80	40	120	50	110
Sept.	200	90	100	100	30	150	90	50	40
Oct.	100	120	90	140	70	170	180	80	90
Nov.	190	90	60	150	70	290	110	80	90
Dec.	140	210	50	60	90	70	130	90	100
Jan. 1972	70	50	140	70	50	80	150	90	90
Feb.	170	60	10	50	170	0	80	20	40
Mar.	60	10	90	80	40	0	20	240	210

Table 3 (Continued)

Date	Fertilizer Treatment Level (Nitrogen/Phosphorus)								
	0/0	0/275	0/550	550/0	1100/0	550/275	550/550	1100/275	1100/550
Total									
Mar. 1971	1360	660	380	930	270	1040	440	670	280
Apr.	20	20	0	20	0	10	10	20	20
May	1060	1610	220	530	400	530	660	520	610
June	1080	1330	580	1010	680	340	750	1240	870
July	770	730	510	560	640	237	500	820	590
Aug.	570	1180	630	350	270	370	770	260	500
Sept.	650	400	580	380	340	320	480	480	420
Oct.	420	460	450	940	150	490	490	230	300
Nov.	750	470	520	440	220	570	410	240	340
Dec.	610	570	520	300	410	280	520	450	510
Jan. 1972	610	430	400	480	360	330	400	540	530
Feb.	1330	410	210	250	550	160	180	240	110
Mar.	240	90	230	330	100	100	140	100	700
$\bar{x}$	9740	8300	5230	6124	4390	4777	5750	5810	5780

was responsible for the general reduction in total population observed in Table 3.

McBrayer and Reichle (1970) reported Collembola densities in the litter of approximately 11,000 organisms per m^2. Pearse (1946) found Acarina populations to be on the order of 9,000 organisms and collembolans to have population densities slightly greater than 3,000, with a total population of approximately 14,000 organisms per m^2. The population value reported by McBrayer and Reichle (1971) represents a rich mesic site, while the estimates of Pearse (1946) represent more xeric conditions. The highest population level recorded in any of the plots was 1610 organisms per m^2 in May 1971. This value presents quite a contrast to the average value for litter invertebrates found by Edwards et al. (1969) and McBrayer and Reichle (1971) of 78,000 and 59,000 respectively. Although Crossley and Hoglund (1962) noted that populations of microfauna tended to be greater in litter bags due either to a more stable microclimate and/or protection from large predators, population levels from this study appear to be extremely low in comparison to literature values. However, population estimates in this study were based on litter bag extractions, and the leaves contained in these bags were representative of only a small segment of the O_1 layer. Thus, the values from this study may not be directly comparable to other studies in which the total litter was sampled.

From a comparison of the total population sums in Table 3, it appears that fertilization (primarily nitrogen) reduced the microfaunal population levels below control levels. This observation is consistent with that of Huhta et al. (1969) who found that when

800 kg/ha of nitrogen was added to a Finnish forest, microfaunal population numbers diminished the first year after fertilization. According to Huhta et al. (1969), pH alteration is the causal mechanism, with members of the order Acarina being particularly sensitive. The questions arising from these results are: (1) did the increased microfloral population associated with nitrogen compensate for the reduced level of microfaunal decomposition, (2) were microfloral populations forced to operate at below optimum level due to a lack of microinvertebrates to precondition the litter, (3) was the microfauna out competed by the microflora, and (4) was microflora standing crop greater because of less grazing?

Red Maple and Black Gum

Phosphorus treatment significantly increased the Acarina population and total microfaunal population in red maple leaf litter, while Collembola populations were not altered. The total population response means for the 0-, 275-, and 550-kg/ha levels of phosphorus at 143, 319, and 201 organisms per m^2 respectively illustrate the positive influence of phosphorus. Based on these response means, the optimum level of phosphorus for microfaunal growth lies between 0 and 550 kg/ha. The addition of phosphorus at some level below 550 kg/ha produces a toxic effect that reduces populations. Acarina population response means (103, 255, and 143 organisms per m^2) exhibited the same response trend to phosphorus as the total population.

Nitrogen addition significantly reduced both Acarina and total population level but did not alter Collembola populations. Total population means dropped from 299 to 207 and 157 organisms per m^2 in response to increased nitrogen level. Acarina means exhibited a similar trend. The changes in pH associated with the hydrolysis of urea were probably responsible for these reductions because of the pH sensitivity of these organisms (Huhta et al. 1969). Nitrogen fertilizer appeared to override the influence of phosphorus as in the case of white oak, but the effect was much more evident in the reduced red maple population levels.

Microfauna in black gum litter did not respond significantly to fertilizer treatments. One might speculate that the pH effects associated with fertilizer application were somewhat mitigated by the higher level of calcium in black gum litter. The mean calcium content of black gum litter during the study period was 27% greater than that of red maple and 14% greater than that of white oak.

Three sampling dates did not provide adequate data to evaluate the response of the microfauna inhabiting black gum and red maple leaf litter. Additional samples should have been taken during the period immediately after fertilization since the greatest pH fluctuations occurred then. Although inadequate as absolute measurements, the values presented in Table 4 do indicate the relative response of the microfauna in two litter types to be considerably different from white oak.

III. WEIGHT LOSS

White Oak

Lunt (1935), Bocock and Gilbert (1957), Kucera (1959), Crossley and Witkamp (1964), and Thomas (1970) reported annual weight losses

Table 4. Acarina, Collembola, and total invertebrate population levels in red maple and black gum leaf litter as a function of fertilizer treatment. Values presented represent the number of organisms per m^2 as determined by Tullgren extraction of red maple and black gum litter bags.

	Fertilizer Treatment Level (Nitrogen/Phosphorus)								
Date	0/0	0/275	0/550	550/0	1100/0	550/275	550/550	1100/275	1100/550
Red Maple									
Acarina									
Mar. 1971	10	486	0	10	10	36	3	10	3
Sept.	140	256	173	36	46	73	83	83	83
Mar. 1972	340	386	423	156	136	656	180	310	320
Collembola									
Mar. 1971	3	70	0	3	0	13	3	10	0
Sept.	13	83	50	46	26	50	40	36	43
Mar. 1972	103	23	30	30	40	133	80	47	77
Total									
Mar. 1971	20	563	60	13	13	60	10	20	3
Sept.	156	353	233	94	120	126	136	126	147
Mar. 1972	473	423	456	200	200	816	407	317	408
$\bar{x}$	649	1139	749	307	333	1002	553	463	558
Black Gum									
Acarina									
Mar. 1971	113	77	93	80	366	177	120	287	226
Sept.	490	490	173	226	737	477	363	300	313
Mar. 1972	137	313	263	83	103	46	213	700	7
Collembola									
Mar. 1971	36	74	17	200	120	33	147	256	33
Sept.	173	22	123	57	47	227	240	210	146
Mar. 1972	93	95	13	73	37	23	226	100	3
Total									
Mar. 1971	150	150	116	283	486	216	270	553	263
Sept.	700	763	343	320	806	710	853	516	510
Mar. 1972	254	416	283	156	146	70	460	86	440
$\bar{x}$	1104	1329	742	759	1438	996	1583	1155	940

ranging from 17 to 60% with most values generally falling in the 30 to 40% loss range. A 31% weight loss occurred during the first 12 months of this study, with an additional 3% loss during the final four months of the study. The 31% loss during the first 12 months of the study was in line with literature values, while the 3% loss during the final four months reflects the reduced amount of readily decomposable material.

The values plotted in Figure 6 represent cumulative weight loss; consequently, any value should be greater than or equal to the preceding value. However, weight increases were recorded in May and October (Figure 6). These increases are attributed to an external input of organic material plus increased fungal activity. The source of the organic material in May was reproductive parts. Grizzard (unpublished data) found the input of reproductive parts to be 2 to 4 g/m^2. Occurring simultaneously with the input of reproductive parts was a sizable increase in the amount of fungal material present in the litter (Table 1, p. 21). The October weight increase was due to the incorporation of small organic particles from freshly fallen litter. Some question could be raised as to whether these two weight increases were really due to the factors suggested or just sample variability. There is little doubt as to the validity of the increases as the material responsible for the increase in bag weight could be easily observed.

Response to phosphorus. Phosphorus additions significantly reduced mean weight loss from 23% at the zero level of phosphorus to 20 and 19% at the 275- and 550-kg/ha levels. Total loss from the plots treated

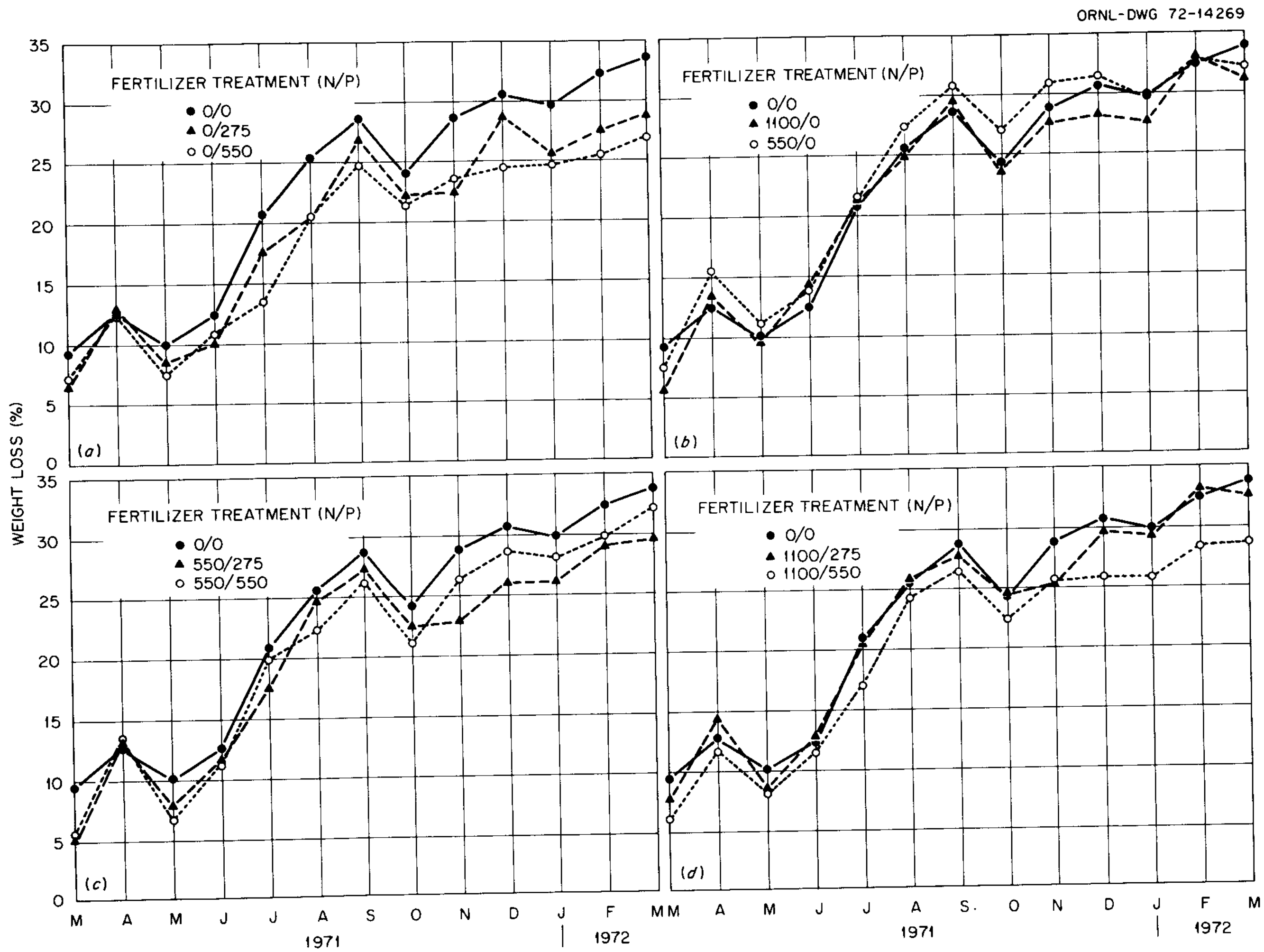

Figure 6. Cumulative weight loss from white oak litter bags following fertilizer application. Standard deviations are presented in Table 15, Appendix B. Phosphorus treatment retarded weight loss (a) and nitrogen stimulated weight loss (b). When nitrogen and phosphorus were combined (c and d) the weight loss response was intermediate to the responses attributed to either nitrogen or phosphorus.

with no nitrogen and 550 kg/ha of phosphorus was 7% below control loss (Figure 6). Phosphorus addition reduced litter decomposition through its detrimental effect on the microflora (Table 1, p. 21). Although the mechanism responsible for these reductions is unclear, phosphorus has been found to have a similar detrimental effect on the growth of higher plants (Curlin 1963). Regression analyses indicated a positive correlation (r = 0.70) between white oak weight loss and microfloral population, while the correlation between white oak weight loss and microfaunal population was of a much lower degree (r = 0.35). Acknowledging the essential contribution of the microfauna to decomposition, it appears that the microflora inhibition due to phosphorus treatment resulted in the observed reduced rates of decomposition.

Response to nitrogen. The addition of organic material with a wide carbon/nitrogen ratio (e.g., litterfall) causes a depletion of available nitrogen in the litter since nitrogen is used for the synthesis of protoplasm by the microorganisms which develop on the material (Tribe 1960; Pauli 1970). It should, therefore, follow that nitrogen additions would increase the level of decomposition. The application of nitrogen to white oak litter significantly increased mean weight loss from 20% at the zero level to 21 and 22% at the 550- and 1100-kg/ha levels respectively. Considering the amount of nitrogen added, a much larger increase in decomposition was anticipated. It appears from these observations that decomposition of O_1 litter was proceeding at near maximum level and that something other than nitrogen was the limiting factor.

Response of Unconfined 0_1 and 0_2 Litter to Fertilization

While the main focus of this study was directed toward an evaluation of the effect of fertilizer on the 0_1 litter component, visual observations made during the course of the study indicated that the 0_2 segment of the forest floor was exhibiting a marked response to nitrogen fertilizer. Consequently, samples of 0_1 and 0_2 litter were collected 1 year after fertilization to determine if a difference in litter weight due to fertilizer treatment could be detected. No alteration of 0_1 litter standing crop due to fertilization could be detected. The 0_2 component did not respond to phosphorus treatment, but there was a significant reduction ($\bar{x}$ = 30 g/m^2) in the amount of 0_2 litter collected from nitrogen-treated plots. The lack of response of the 0_1 component was to be expected since a large portion of the leaf material fell approximately eight months after fertilization. Weight estimates for 0_1 litter presented in Table 5 agree closely with the mean estimate (890 g/m^2) for similar upland oak sites on Walker Branch Watershed (Henderson 1972a). Estimates of 0_2 litter weight (Table 5) were considerably less than the 1800 g/m^2 reported by Henderson (1972a). These differences were due in part to fertilizer treatment, but may also reflect site differences.

The hypothesis that some factor other than nitrogen (e.g., moisture) was limiting the decomposition of the 0_1 seems to be borne out by a comparison of the carbon/nitrogen ratios for the unconfined 0_1 and 0_2 litter. The 0_2 ratio at 40 was approximately twice that of the 0_1 at 23. Consequently when nitrogen was added to the 0_1, there was less reduction

Table 5. Mean weight (g/m^2) of O_1 and O_2 litter collected from the study plots in March 1972. The number in parentheses is the standard deviation of the treatment mean.

Litter Horizon	Fertilizer Treatment Level (Nitrogen/Phosphorus)								
	0/0	0/275	0/550	550/0	1100/0	550/275	550/550	1100/275	1100/550
O_1	748(180)	824(200)	812(121)	868(216)	796(120)	748(136)	904(168)	704(128)	688(224)
O_2	884(226)	624(88)	596(136)	536(216)	684(136)	548(72)	640(64)	612(104)	660(65)
O_1+O_2	1632	1448	1408	1404	1480	1296	1544	1316	1348

of the carbon/nitrogen ratio, while the O_2, with a wider carbon/nitrogen ratio, responded significantly.

The addition of urea produced a general collapse of the litter structure. Associated with this collapse was a certain degree of solubilization of organic matter. This solubilization was undoubtedly responsible for a portion of the weight loss attributed to nitrogen. Solubilization losses will receive further consideration in the nutrient dynamics section.

Red Maple

Response to phosphorus. Red maple leaf litter did not respond significantly to phosphorus addition (Figure 7). When the treatment responses plotted in Figure 7 are compared, the weight loss from plots treated with phosphorus was consistently less than control loss, even though the phosphorus main treatment effect was not statistically significant. It appears that red maple leaf litter responded to phosphorus treatment, but the higher levels of variance associated with the red maple means probably prevented the detection of a significant response (Table 16, Appendix B). In retrospect, a better estimate of red maple weight loss dynamics could have been obtained if additional samples had been taken in April, May, August, and October since these were the months in which the greatest microbial activity occurred (Table 1, p. 21).

Response to nitrogen. Red maple weight loss responded significantly to nitrogen treatment. Mean weight losses as a result of treatment with

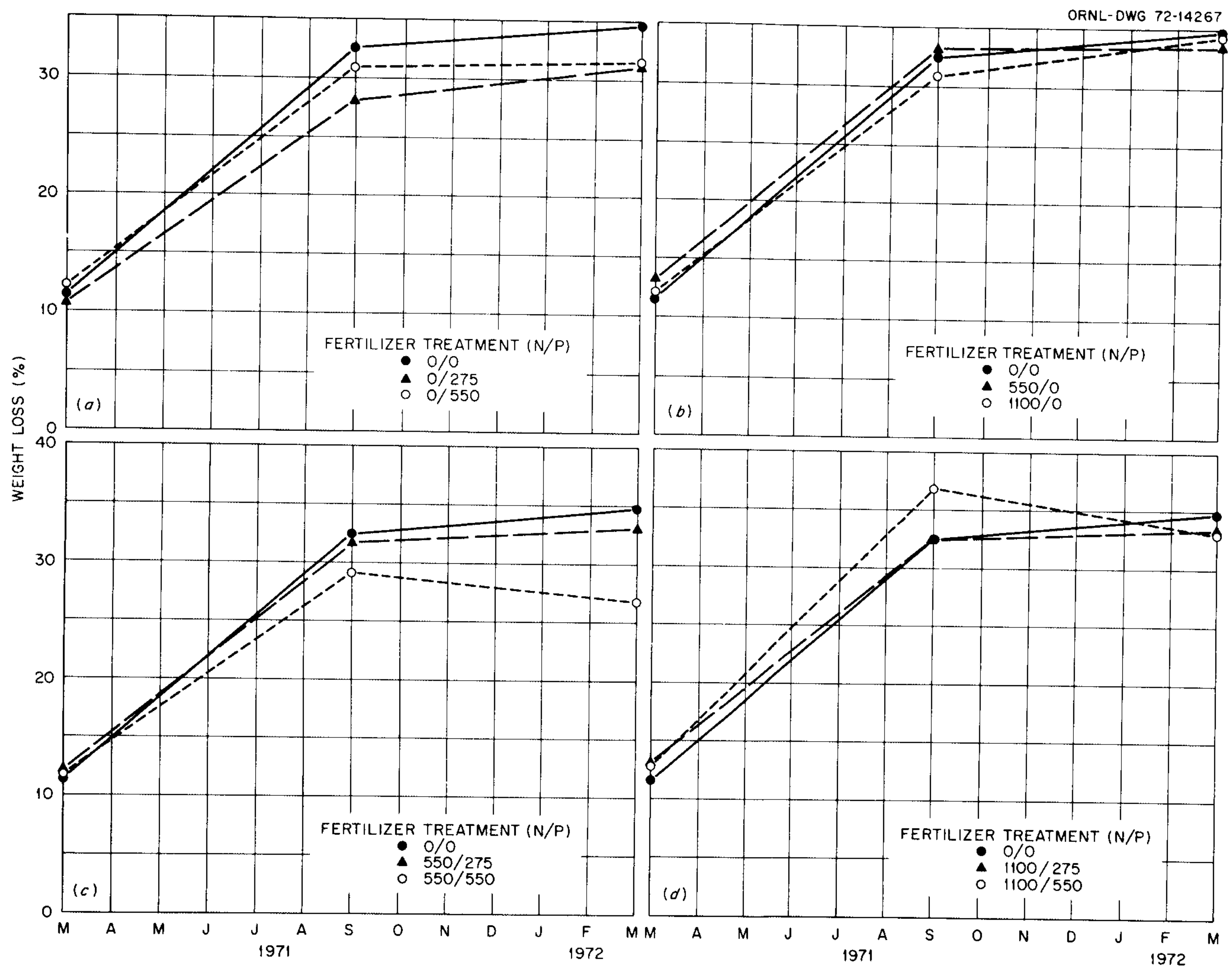

Figure 7. Cumulative weight loss from red maple litter bags following fertilizer application. Standard deviations are presented in Table 16, Appendix B. Weight loss from plots treated with phosphorus alone or in combination with nitrogen were generally below control weight loss.

0, 550, and 1100 kg/ha of nitrogen were 25, 25, and 27% respectively. Mean weight loss from red maple leaf litter was approximately 4% greater than the loss from white oak. The lack of inhibitory agents, such as tannins, enabled microorganisms to decompose red maple leaf litter faster than white oak. While the application of nitrogen increased the decomposition of red maple, the magnitude of the increase was no greater than that observed for white oak.

Black Gum

Comparison of total weight loss values for red maple and black gum indicated that black gum weight loss was much greater (Figures 7 and 8). Weight loss from black gum controls (45%) was approximately 10% greater than the white oak or red maple weight loss. Total loss values for red maple over an annual cycle reported by Shanks and Olson (1961) and Thomas (1970a) ranged from 32 to 55%, while other literature values range from 27 to 43%. The red maple total weight loss value (35%) agrees with literature estimates. However, black gum total loss (45%) was below the 55 and 85% annual losses found by Thomas (personal communication) and Monk (1971) respectively.

Response to phosphorus and nitrogen. Both the 275- and 550-kg/ha levels of phosphorus reduced weight loss by 3%. The actual magnitude of the reduction was no greater in black gum litter than in white oak or red maple. Nitrogen additions significantly increased black gum decomposition. The absolute increase at approximately 2% was similar to the increases noted for white oak and red maple. These observations suggest that the base rate of decomposition of a particular species is

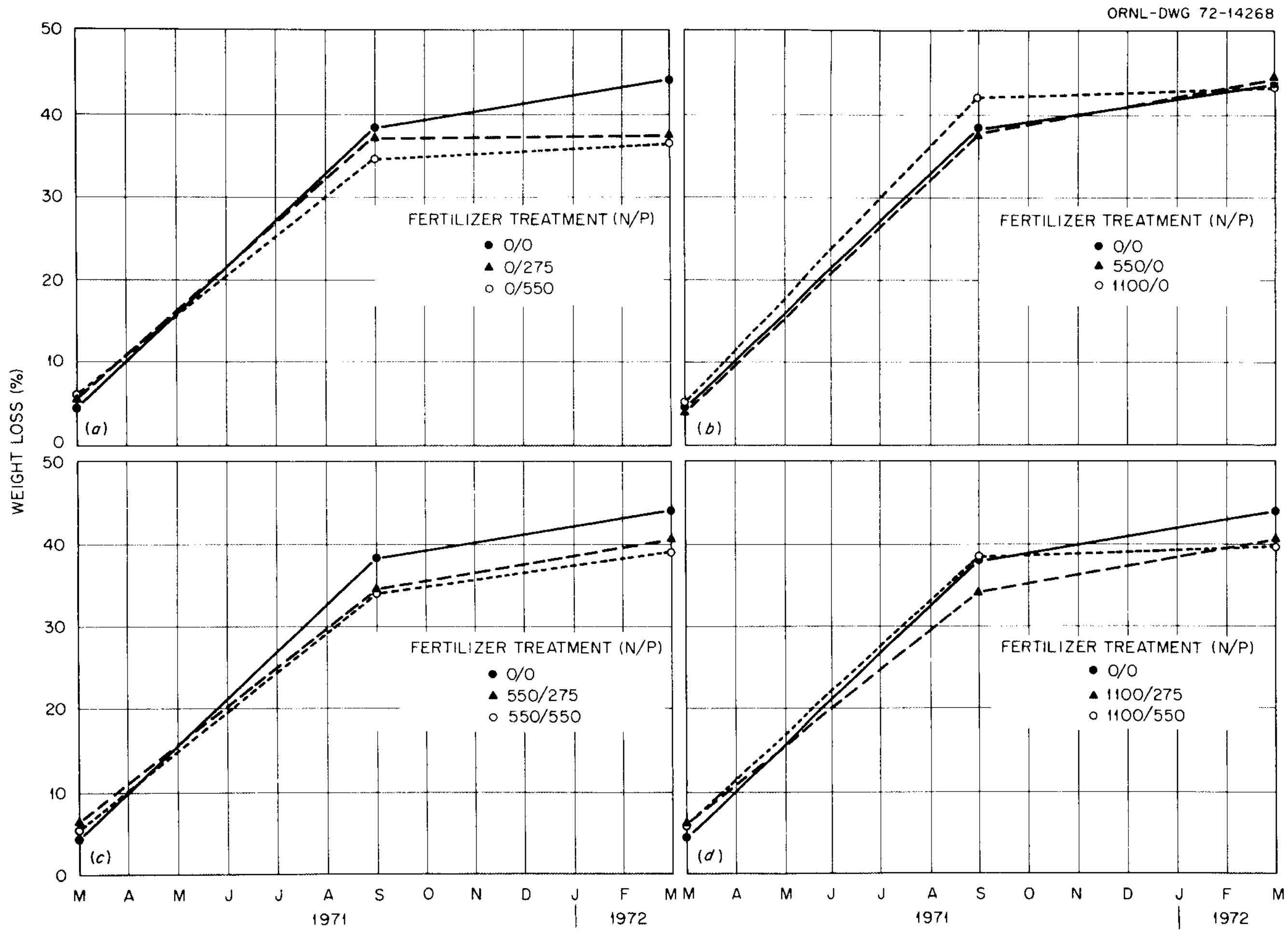

Figure 8. Cumulative weight loss from black gum litter bags following fertilizer application. Standard deviations are presented in Table 17, Appendix B. Although the level of decomposition was higher for black gum, the magnitudes of the responses to nitrogen and/or phosphorus were equivalent to the white oak and red maple responses.

controlled by internal factors interacting with microorganisms, and that the addition of chemical fertilizers has the same effect on these organisms no matter what their substrate. This particular point warrants additional investigation, since it could simplify the prediction of the effect of a fertilizer addition on litter decomposition.

White Oak, Red Maple, and Black Gum Response to the NP Interaction

The NP interactions were significant for both white oak and red maple weight loss (Figure 9), but not for black gum. As the phosphorus level was increased, while nitrogen level was held constant, the weight loss from white oak litter bags declined in all cases except one; the 550/550 treatment. No biological explanation for the white oak 550/550 response can be offered. Further statistical evaluation revealed that the 550/550 response was not significantly different from the 1100/550 response, while both were significantly different from the 0/550 response. The 550/550 response appears to be an artifact. The red maple NP interaction (Figure 9) was different. Decomposition at the 1100-kg/ha level of nitrogen continued to increase even in the presence of 550 kg/ha of phosphorus. The 0- and 550-kg/ha nitrogen levels exhibited similar response trends except that the 0/550 response deviated slightly. Further statistical evaluation revealed that the 0/550 response was not significantly different from the 550/550 response, but was significantly lower than the 1100/550 mean.

The explanation appears to be that both nitrogen and phopshorus were limiting red maple decomposition and 550 kg/ha of nitrogen was not sufficient to overcome the nitrogen shortage and stimulate microbial

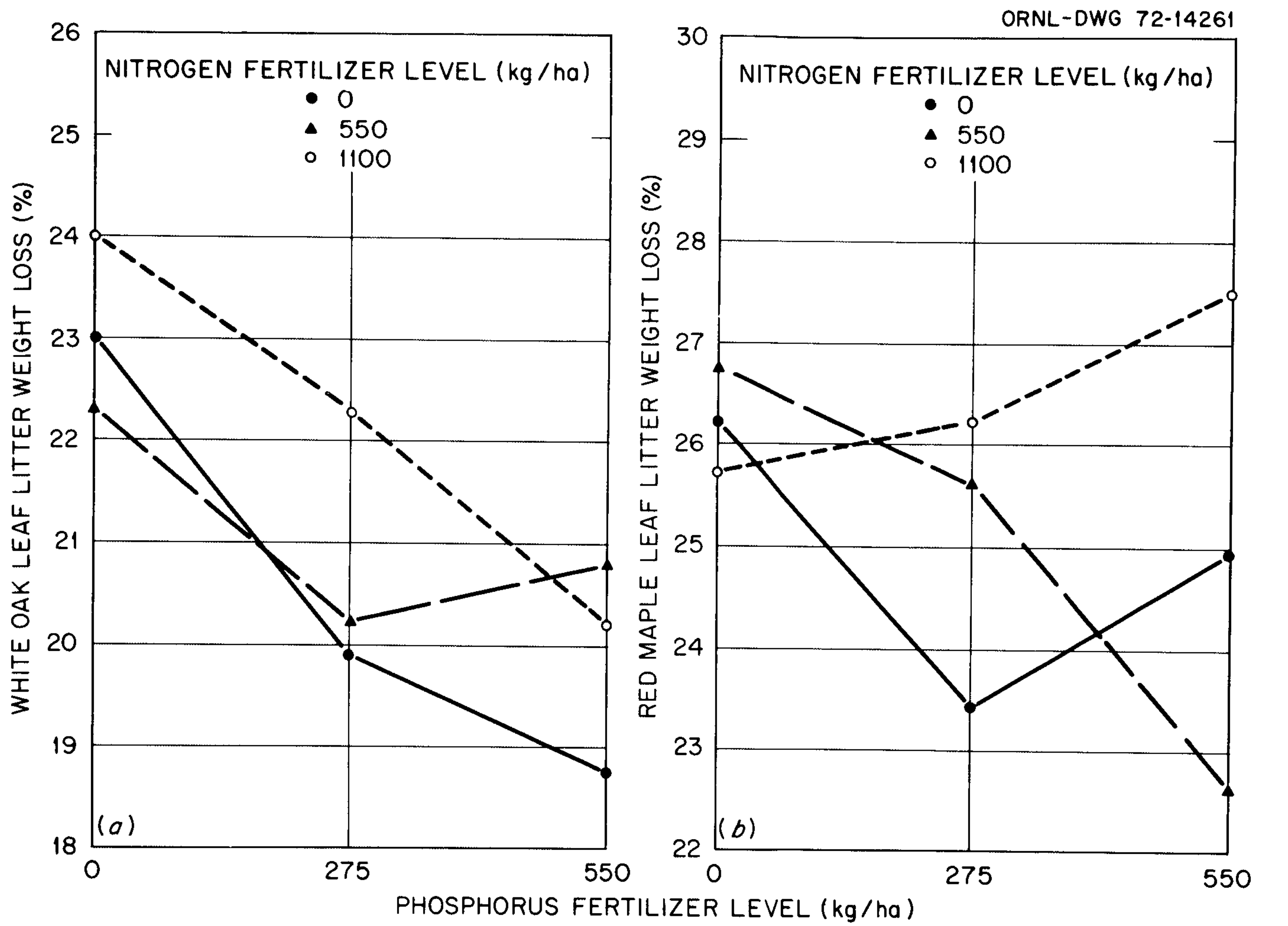

Figure 9. Mean weight loss response of white oak and red maple leaf litter to the interaction of nitrogen and phosphorus treatments. White oak weight loss declines as phosphorus level was increased while nitrogen level was held constant (a). Both nitrogen and phosphorus were limiting red maple decomposition (b) and 550 kg/ha of nitrogen was not sufficient to overcome the nitrogen shortage.

growth and phosphorus utilization. Based on data summarized in Figure 7, the responses to nitrogen and phosphorus at the 1100/275 and 1100/550 levels (7d) are different from the responses at the 550/275 and 550/550 levels (7c). The conclusion suggested is that nitrogen and phosphorus have an antagonistic effect when applied together and that the biological response differs depending on whether the two elements are applied together or separately.

The Interaction of Nitrogen and Phosphorus Main Treatments and Time

The physical and biological factors regulating decomposition processes are time-dependent. A fertilizer addition could interact with time to modify the decomposition rate. From a managerial or environmental point of view, it is essential to know how long a particular level of nitrogen or phosphorus can be expected to influence the normal effect of time or if the response is due to the treatment or time alone.

An analysis of variance indicated that the nitrogen-time (NT) and phosphorus-time (PT) interactions were not significant for white oak and red maple. The microfloral population levels interacting with fertilizer treatment thereby alter total decay rather than the interaction of fertilizer treatment and time. The black gum PT interaction was significant because when compared to the zero level greater inhibition of decomposition by phosphorus occurred from March to September but not from September to March (Figure 10). The effect of phosphorus on weight loss could still be detected at the end of the study, although the responses associated with the 275 and 550 levels did not differ from

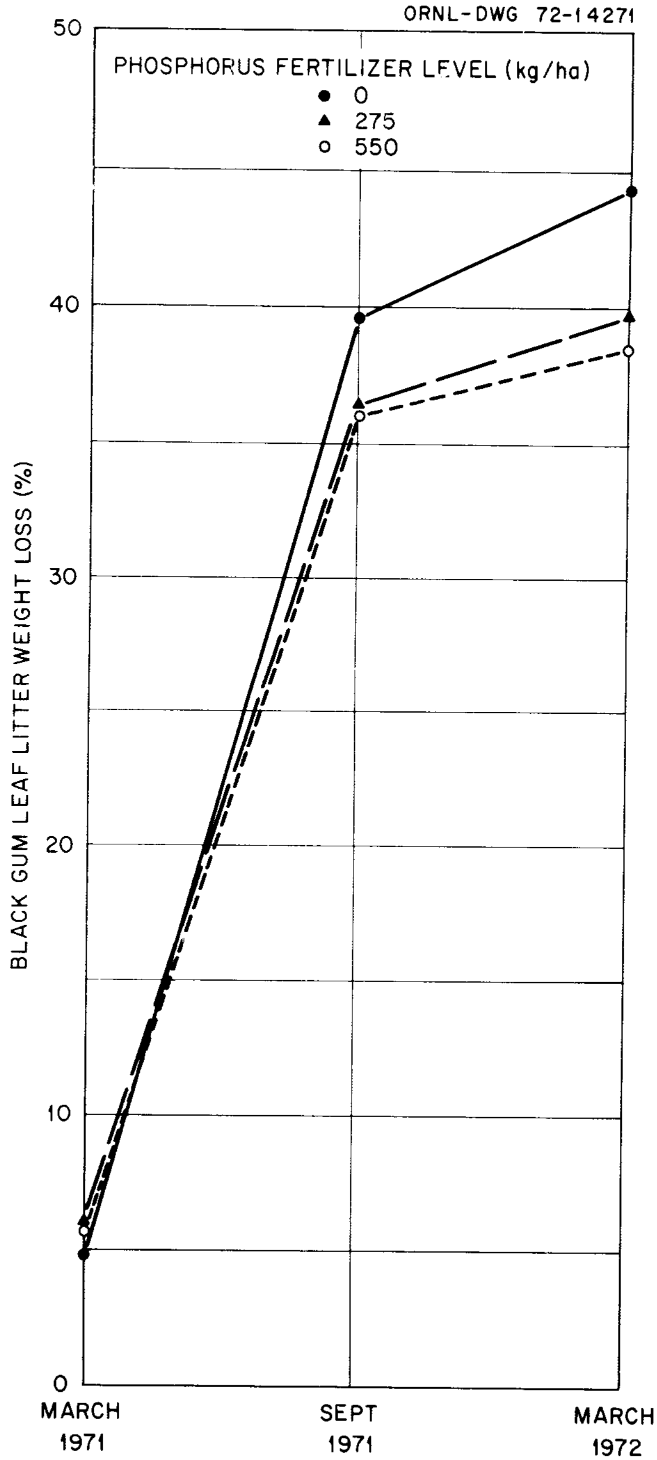

Figure 10. Response of black gum leaf litter cumulative weight loss to the interaction of phosphorus treatment and time. Both the 275 and 550 levels of phosphorus produced essentially the same degree of inhibition.

each other significantly. The black gum NT interaction was not statistically significant.

IV. NUTRIENT DYNAMICS

Nutrient cycling is interdependent with all components of the ecosystem. Decomposition is adjusted to nutrient uptake, and uptake is adjusted to decomposition (Likens et al. 1970). The ability of forests to maintain large amounts of nutrients in circulation appears to explain the relatively high productivity of forests on soils of low nutrient status. Forest soils, in contrast to agricultural soils, restrict the losses of nutrient elements which occur through leaching (Overrein 1969). However, the intensification of forest management, especially the addition of chemical fertilizers, may bring about lasting changes in the nutrient status of two principal components in the nutrient cycle, the litter and mineral soil.

The nutrient status of various types and forms of forest litter has been well documented. Most of the pertinent literature on litter nutrient status was summarized by Rodin and Bazilevich (1967), and the literature on the nutrient status of the soil solution was summarized by Altman and Dittmer (1966). The dissolved nutrients of soils are not uniformly distributed in the aqueous phase due to the influence of electrostatically charged soil particles (Altman and Dittmer 1966). Hence the chemical characteristics of the soil solution cannot be determined directly but must be inferred from analysis of extracts. The nutrient concentration of the solution extracted from a soil is determined by the number of soluble anions, principally nitrate, sulfate, bicarbonate, and chloride, and is inversely related to the soil moisture content (Altman and Dittmer 1966). Thus, the mineral element composition of the soil solution is influenced by biological activity, solubility of certain compounds, and total concentration of the various elements. On the other hand, the elemental composition of the litter is controlled primarily by biological activity and secondarily by physical leaching. Since the nutrient contents of both the litter and soil solution are intimately related via the annual nutrient cycle, any change in one ultimately will be reflected in the other.

Physical and Chemical Parameters

Effect of urea on litter structure. The application of urea resulted in a general collapse of the physical structure of the litter, especially the more humified O_2 portion. Urea did not seem to affect the physical structure of the O_1 as much as it did the O_2. This structure collapse of the litter as a result of heavy urea fertilization has been attributed in part to the increase in pH associated with urea hydrolysis and in part to the exchange of organically sorbed cations with ammonium, which increases the solubility of humic material in water (Ogner 1972; Ogner and Schnitzer 1970; Bengston 1970). The aqueous solution passing through the litter is capable of transporting a substantial amount of dissolved organic material into the mineral soil (Ogner 1972; Bengston 1970). Humic and fulvic acids constitute a major portion of the organic material collected in soil leachate, and these acids are also responsible for the dark color associated with leachate collected from urea-treated soil and litter (Martin and Haider

1971). The influence of urea on the coloration of the soil solution can be seen in Figure 11. The relatively clear samples on the first level were collected from each treatment plot just prior to fertilization. The leachates in the bottles on the second level were collected immediately after fertilization and reflect a high degree of dissolution of humus. The percent transmission values summarized in Table 6 quantify the relative turbidity in comparison with distilled water for each of the treatments. The turbidity of the soil solution was not significantly altered by phosphorus fertilization, while the turbidity of leachate collected from plots treated with nitrogen was significantly increased. The mean percent transmission for the zero nitrogen level was 79% compared to 76 and 73% for the 550-and 1100-kg/ha increments. The NP interaction was also significant, indicating that nitrogen and phosphorus together produced a turbidity change different from that attributed to nitrogen or phosphorus. When nitrogen and phosphorus were actually applied together they produced an intermediate weight loss response. That was not the case for the turbidity of the soil solution; nitrogen and phosphorus together lowered the percent transmission values more than nitrogen did. The means for the 550/275, 550/550, 1100/275 and 1100/550 treatments at 76, 72, 74, and 71% were 1 to 10 units below the nitrogen-only means. The contribution of phosphorus to increasing the level of dissolution is unknown. The actual amount of organic material moving in the soil solution as a result of fertilization was not determined; however, this parameter should be quantified in future studies in order to differentiate the organic material decomposed by microorganisms from that lost due to the increased solubility of humic

PHOTO 2935-72A

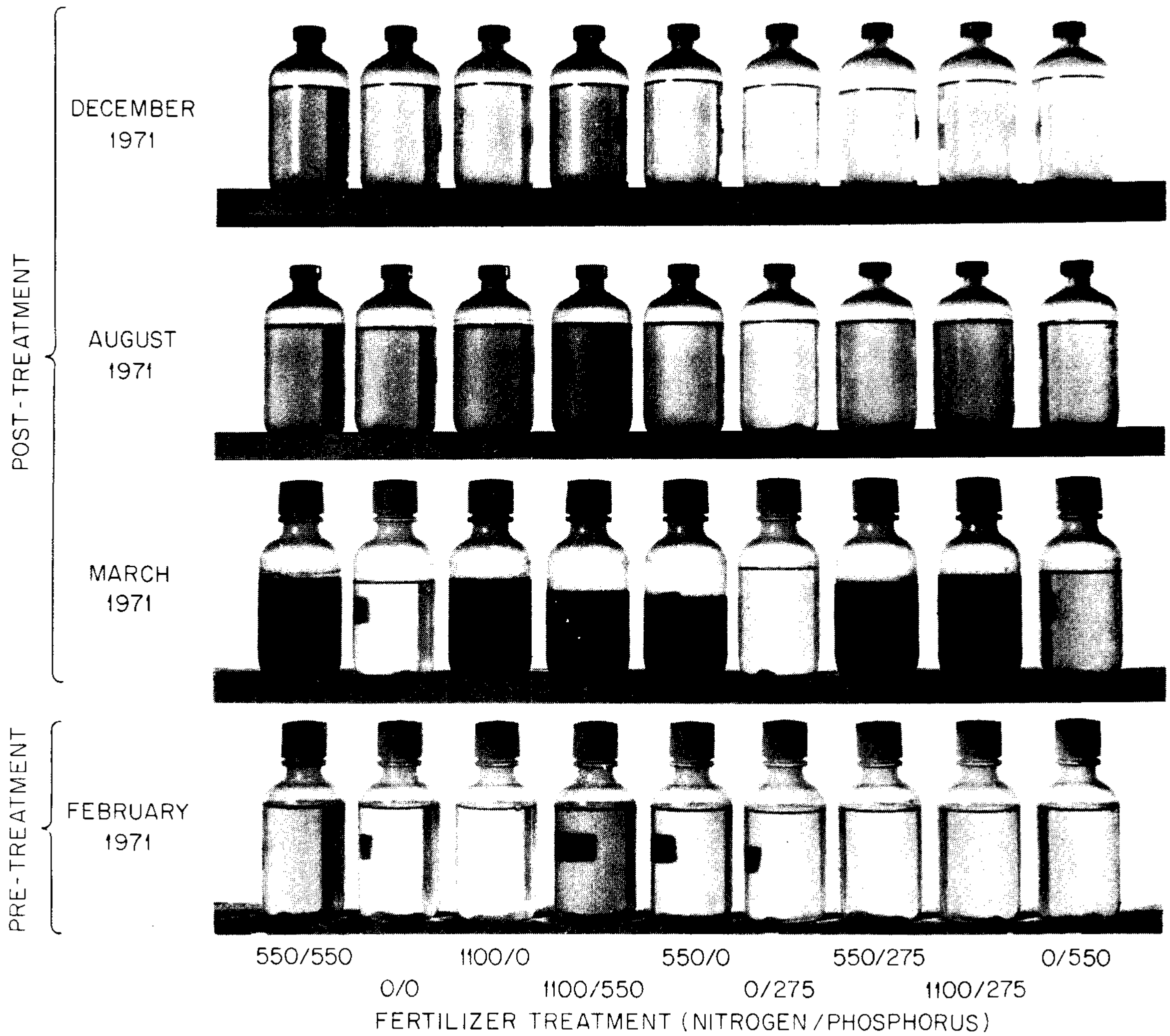

Figure 11. Relative change in coloration of the soil solution as a result of fertilizer treatment; (February) prior to fertilization, (March) immediately after fertilization, (August) six months after fertilization, and (December) after annual leaf fall.

Table 6. Measurements of soil solution turbidity expressed as percent light transmitance (410 microns).

Date	Sample	Fertilizer Treatment Level (Nitrogen/Phosphorus)								
		0/0	0/275	0/550	550/0	1100/0	550/275	550/550	1100/275	1100/550
Mar. 1971	15	88	93	84	67	29	30	59	61	34
Apr. 1971	16	96	95	89	68	56	56	58	56	56
	17	96	93	90	66	54	55	59	54	54
	18	*								
	19	86	94	90	68	56	60	64	56	56
Mar. 1971	20	94	85	74	72	59	68	61	58	57
	21	89	88	93	85	73	76	81	76	75
	22	81	82	80	53	31	49	52	47	42
	23	*								
	24	85	85	85	86	78	73	82	42	59
June 1971	25	*								
	26	*								
	27	87	88	83	91	89	86	81	44	71
	28	*								
July 1971	29	*								
	30	92	88	89	92	92	91	90	90	77
	31	89	91	90	90	93	90	87	91	84
	32	86	89	88	89	90	85	88	89	82
Aug. 1971	33	84	85	85	87	85	87	84	89	77
	34	86	81	84	84	84	87	80	86	80
	35	90	77	89	89	89	91	89	89	83
	36	*								
	37	*								
Sept. 1971	38	*								
	39	*								
	40	84	93	85	78	83	83	91	77	79
	41	82	84	85	84	80	82	84	82	78
Oct. 1971	42	*								
	43	86	91	85	81	91	87	86	84	87
	44	87	83	89	88	86	92	86	85	83
	45	*								
Nov. 1971	46	*								
	47	*								
	48	84	86	85	88	82	80	79	87	73
	49	*								
	50	83	80	89	82	73	85	85	81	81
Dec. 1971	51	82	85	89	86	81	83	83	83	84
	52	77	89	83	77	73	78	79	78	81
	53	71	79	81	76	68	73	72	73	73
	54	71	84	80	78	75	69	70	74	70
Jan. 1972	55	76	82	84	82	77	79	70	83	77
	56	71	82	80	79	68	72	70	78	73
	57	66	82	68	75	68	62	63	68	65
	58	73	80	89	83	78	76	76	81	75
	59	*								
Feb. 1972	60	81	80	91	88	83	81	72	80	49
	61	81	85	87	84	80	81	77	75	79
	62	77	90	86	86	75	80	78	78	79
	63	81	82	84	84	79	81	78	81	77
Mar. 1972	64	80	80	85	83	78	81	78	84	74
	65	*								

materials. The dark color associated with nitrogen treatment decreased with time and was undetectable by the end of July. The samples of leachate collected in December (Figure 11) are presented to illustrate the influence of tannins on the coloration of the soil solution. The tannins reduced slightly the transmission values for all treatments in December and January (Table 6).

Changes in pH associated with urea hydrolysis. Closely associated with the dissolution of organic matter are the pH changes associated with the hydrolysis of urea. As previously noted by Overrein and Moe (1967), Bengston (1970), Buckman and Brady (1969), Tisdale and Nelson (1966) and others, the addition of urea to the litter increased the pH of the soil solution. It then gradually declined to a level below that recorded prior to treatment. The pH of the soil solution was significantly altered by nitrogen treatment. The increase in pH associated with urea hydrolysis and the gradual reduction of pH through time can be seen in Table 7. A comparison of the mean pH response during the study period indicated that only the 550/550 treatment at 5.8 exhibited the classical response and dropped below the control mean of 6.1. Phosphorus treatment did not significantly alter soil solution pH.

The shifts in litter and soil solution pH associated with nitrogen treatment are important since pH is significant in determining the availability as well as susceptibility of certain ions to leaching, immobilization, and volatilization (Black 1957, Bear 1964, Overrein and Moe 1967, Meyer et al. 1961, Wahhab et al. 1960). The pH of

Table 7. Summary of soil solution pH values for all fertilizer treatment combinations for the March 1971-March 1972 period.

Date	Sample	Fertilizer Treatment Level (Nitrogen/Phosphorus) 0/0	0/275	0/550	550/0	1100/0	550/275	550/550	1100/275	1100/550
Mar. 1971	15	6.3	6.2	5.4	7.5	8.4	6.7	7.5	8.4	8.0
Apr. 1971	16	6.3	6.2	5.7	7.5	8.7	5.7	8.0	8.7	8.1
	17	6.3	6.3	6.5	7.3	8.2	6.9	7.2	7.6	7.8
	18	*								
	19	6.1	6.1	5.9	6.7	8.0	6.9	6.8	7.5	7.6
May 1971	20	6.0	6.3	6.0	6.6	7.5	6.8	6.2	7.1	7.2
	21	5.9	6.2	5.9	6.0	7.2	6.4	5.5	6.6	6.4
	22	5.8	6.4	6.2	5.9	6.8	6.6	5.3	6.5	6.4
	23	*								
	24	5.9	5.7	6.0	5.6	5.9	6.3	5.7	7.0	5.8
June 1971	25	*								
	26	*								
	27	6.1	6.6	5.7	5.3	5.7	5.7	6.0	6.0	6.1
	28	*								
July 1971	29	*								
	30	5.7	6.4	5.7	5.6	5.3	5.7	5.5	5.4	6.2
	31	5.9	6.4	5.5	5.5	5.5	5.6	5.7	5.2	6.1
	32	5.9	6.3	5.4	5.4	5.4	5.6	5.2	5.3	6.0
Aug. 1971	33	5.8	6.4	5.4	5.4	5.5	5.6	5.1	5.5	5.9
	34	5.6	6.3	5.4	5.6	5.8	5.5	5.2	5.5	5.9
	35	5.7	6.5	5.7	5.6	6.0	5.6	5.9	5.7	6.1
	36	*								
	37	*								
Sept. 1971	38	*								
	39	*								
	40	5.7	6.1	5.5	5.8	5.7	5.4	4.9	5.4	5.9
	41	5.5	6.7	5.9	6.4	6.1	6.0	6.1	5.6	6.3
Oct. 1971	42	*								
	43	5.8	6.6	6.3	6.3	6.1	5.9	5.5	6.2	6.2
	44	6.1	6.4	6.2	6.2	6.0	6.1	6.4	5.6	6.5
	45	*								
Nov. 1971	46	*								
	47	*								
	48	5.9	6.7	6.1	6.8	6.6	6.1	6.2	6.5	6.8
	49	*								
	50	5.8	7.1	6.5	6.4	6.0	6.2	6.4	6.1	6.3
Dec. 1971	51	6.7	6.6	6.2	6.3	6.4	6.0	5.5	5.6	6.2
	52	6.1	6.3	6.2	6.2	6.4	6.0	5.4	5.8	6.3
	53	6.1	7.1	6.3	6.3	6.5	6.1	5.7	6.0	6.6
	54	6.3	7.1	6.3	6.4	6.6	6.2	5.7	6.1	6.6
Jun. 1972	55	6.4	6.6	6.4	6.4	6.5	6.1	5.6	6.0	6.6
	56	6.5	6.8	6.5	6.6	6.6	6.3	5.7	6.3	6.8
	57	6.4	7.1	6.8	6.7	6.7	6.5	5.9	6.4	6.9
	58	6.6	7.1	6.6	6.6	6.7	6.7	5.9	6.4	6.8
	59	*								
Feb. 1972	60	6.4	6.8	6.6	6.8	6.3	6.6	4.9	6.6	7.1
	61	6.7	6.9	6.7	7.0	6.8	6.6	4.9	6.5	7.0
	62	6.6	7.4	6.8	7.6	7.2	6.7	5.8	6.9	7.2
	63	6.8	6.4	6.9	6.5	6.4	6.1	5.9	6.3	6.6
Mar. 1972	64	6.9	6.8	6.6	6.6	7.0	6.4	6.0	6.4	6.9
	65	*								

the litter and soil is important since pH alters nutrient availability chemically, which in turn exerts control over biological activity. If the lack of a significant soil solution pH response to phosphorus treatment is assumed to be indicative of the response of the litter pH to phosphorus treatment, then the reduction in microfloral populations due to phosphorus treatment would appear to be due to chemical toxicity or limiting parameters other than pH. Testing of this hypothesis warrants further study.

Estimates of soil solution volume. PROSPER, a phenomenological model developed to simulate atmosphere-plant-soil moisture relations on a day-to-day basis using standard National Oceanic and Atmospheric Administration local climatological data, was used to estimate the volume of water moving through the litter and top 10 cm of the mineral soil (Goldstein and Mankin 1972). Taking into consideration attrition due to interception (23 cm), evaporation (23 cm), and transpiration (45 cm), as determined by Sheppard *et al*. (1973), it appears that the lysimeter estimate (154 cm) compared to total precipitation input (165 cm) was an overestimate due to the lysimeter drawing soil water from an area greater than the soil column directly above the lysimeter plate. Figure 12 illustrates the relationship between precipitation and lysimeter volume estimates. The PROSPER estimate (65 cm) was empirically judged to be more realistic. Consequently, subsequent computations are based on the PROSPER values.

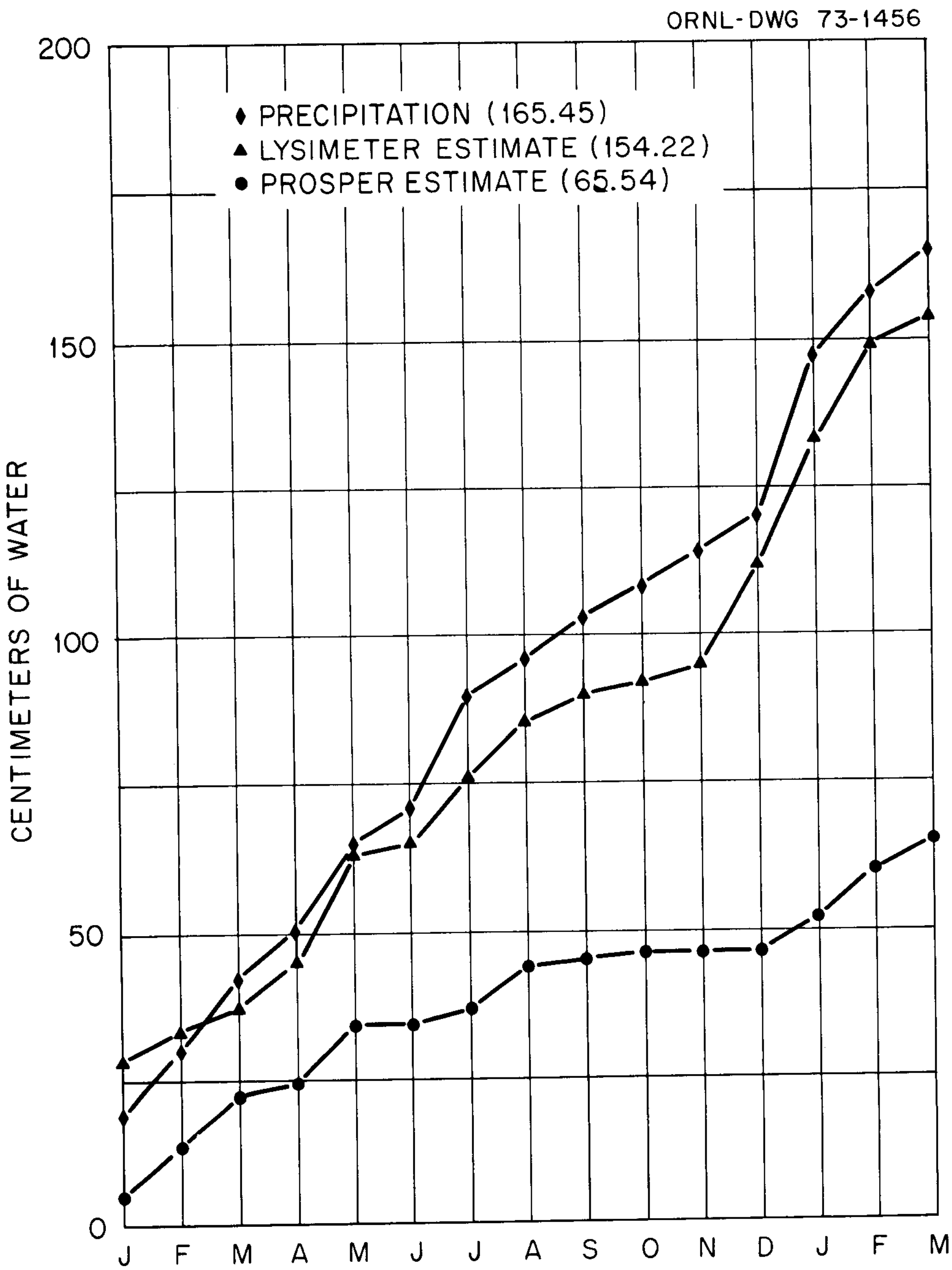

Figure 12. Cumulative precipitation input and estimates of the volume of water passing through the litter and top 10 cm of the mineral soil based on the volume of water collected by tension lysimeters and on PROSPER computations.

V. NITROGEN

To maintain productivity and thus perpetuate the cycling of all elements, nitrogen must be available (Ovington 1960). Nitrogen added to the system by precipitation, fertilization, or microbial fixation of atmospheric nitrogen may be taken up by plants, immobilized as a result of microbial activity, fixed in a non-exchangeable form, or lost through volatilization and/or leaching. The major portion of the nitrogen taken up by plants is eventually returned to the soil either by litter fall or root mortality. Since leaves contribute 75 to 85% of litter input, most of the nitrogen returning to the litter comes from leaf deposition (Rodin and Bazilevich 1967). The nitrogen content of leaf litter varies according to the species. Grizzard (unpublished data) found a mean nitrogen concentration of 0.59% for freshly deposited leaf litter on Walker Branch Watershed. On a weight basis this constitutes approximately 3 g/m^2 of nitrogen per year. The nitrogen content of freshly deposited white oak litter determined in this study was 0.62%.

White Oak

Nitrogen in white oak litter. The weight of nitrogen in white oak litter bags increased from 44 mg/bag to 58 mg/bag during the four months prior to fertilization. After fertilization, the weight of nitrogen increased steadily in most of the treatments through May, and some through July, and then generally declined in August (Figure 13). Weight loss during the same time period ranged from 14 to 22%. Nitrogen from sources other than added fertilizer was immobilized biologically. This hypothesis

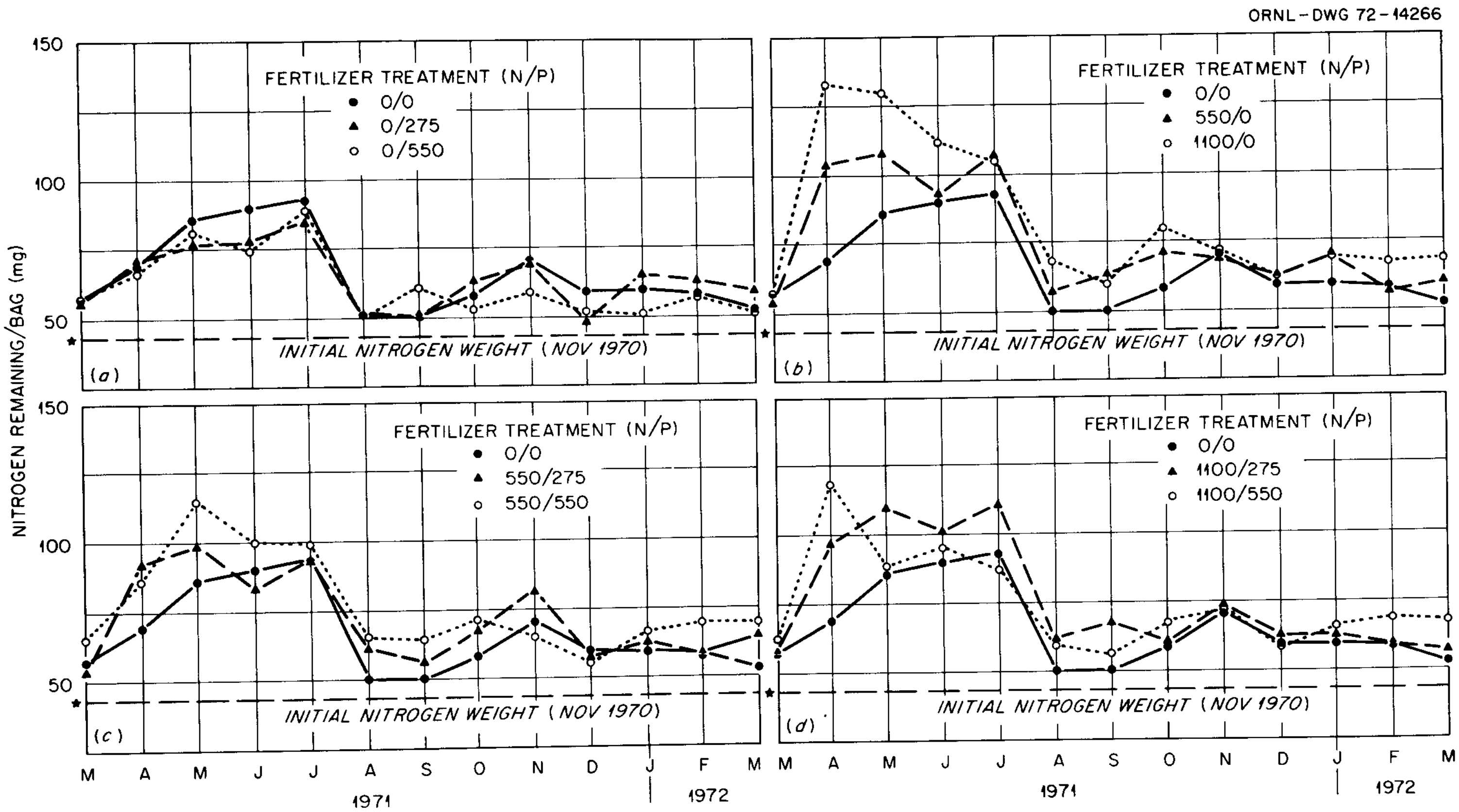

Figure 13. Temporal distribution of nitrogen remaining in white oak litter bags following application of fertilizer treatments. Standard deviations are presented in Table 21, Appendix D. The nitrogen content of white oak litter bags treated with nitrogen (b, c, and d) achieved peak nitrogen content within 1 to 2 months after fertilization, while white oak bags not treated with nitrogen (a) did not reach peak nitrogen content until 4 months after fertilization.

is supported by the responses noted for the 0/0, 0/275, and 0/550 treatments in which an increase in nitrogen weight occurred even though no nitrogen fertilizer was added (Figure 13a). These data indicate that nitrogen was translocated from either the underlying litter or mineral soil by microorganisms colonizing the litter. There was also some nitrogen input in through-fall and in precipitation, as well as microfloral fixation of atmospheric nitrogen. The fact that nitrogen concentration continued to increase while the weight of litter declined indicates partial recycling by the microflora.

Influence of microflora on nitrogen weight in white oak litter. Substantial populations of microfloral organisms were present in the litter during most of the study (Table 1, p. 21). Regression analyses considering nitrogen as the dependent variable and bacteria, fungi, and total microflora population as independent variables were performed. The weight of nitrogen in white oak litter bags was most closely correlated with bacterial population level ($r = 0.80$). The simultaneous drop in both nitrogen weight and bacterial population level in August further indicates that significant biological transformation and immobilization of naturally occurring nitrogen occurred in addition to that derived from fertilizer sources. Fiedler and Weetman (1971), who reviewed the work of several European authors, noted that up to 20% of the urea-nitrogen added to litter may be bound chemically, while an additional 10 to 18% may be immobilized in microorganisms. Thus approximately 38% of the nitrogen added from a urea source could be fixed or immobilized in the litter.

The drop in nitrogen weight in August was probably due to accelerating litter weight loss (Figure 6, p. 35). Even though microbial populations remained high (Table 1, p. 21), the loss of substrate was increasing at a rate too great to be offset by microbial immobilization. The slight increase in nitrogen weight which occurred in all treatments in October and November was due to the immobilization of nitrogen leached from the incoming litter and to the increase in weight of the litter bags due to organic input. Any increase in bag weight would result in an increased nitrogen weight since the weight of nitrogen remaining was calculated by multiplying the concentration by the weight of organic material remaining in the litter bag. Consequently, it is doubtful that the nitrogen weight increase observed in white oak litter was of the magnitude calculated. After the fall peak, the nitrogen weight in the litter bags declined steadily in conjuction with the loss of organic substrate. At the termination of the study the nitrogen weight per bag was still 1.1 to 1.5 times greater than the initial weight (Figure 13). During the final months of the study, the nitrogen values of treated plots, though significantly higher than control level, were essentially equivalent. Thus the initial effect of fertilization on nitrogen content lasted from 5 to 8 months, depending on treatment.

<u>Response of litter nitrogen to fertilizer treatment</u>. Phosphorus addition reduced nitrogen weight significantly; nitrogen addition increased nitrogen weight significantly; and the interaction response of nitrogen and phosphorus was significantly different from the response attributed to either the nitrogen or phosphorus main treatments. The

response of nitrogen weight to fertilizer treatment was due to increased microfloral populations, primarily bacteria. Earlier discussions established the relationship between bacterial population level and nitrogen weight and the differential effects of nitrogen and phosphorus treatments on these populations. Therefore, the response of white oak litter nitrogen weight to fertilization primarily reflects the response of the microflora to fertilization. All nitrogen weight curves (Figure 13, p. 59) reflect a degree of immobilization of nitrogen from normal sources plus an additional increment due to the amount of nitrogen added.

The response of nitrogen weight to all three levels of phosphorus through time was equivalent. Consequently, no significant PT interaction was detected. The interaction of nitrogen with time was significant (Figure 14). A mean comparison indicated that the 550- and 1100-kg/ha nitrogen levels were not significantly different after the June sample, but both were significantly different from the zero level response throughout the study. In biological terms this means that added nitrogen through its effect on the microflora was able to speed the decomposition of white oak litter, thus reducing the length of time required to decompose a given amount of litter.

The plots treated with 1100-kg/ha of nitrogen achieve peak nitrogen weight immediately after fertilization due to the high concentration of nitrogen applied, while the plots treated with 550-kg/ha do not peak until the following month. Due to the lower nitrogen concentration at the 550-kg/ha level a certain amount of time was required before the microflora could achieve peak accumulation. This hypothesis is verified by the fact that the 1100-kg/ha peak is only slightly

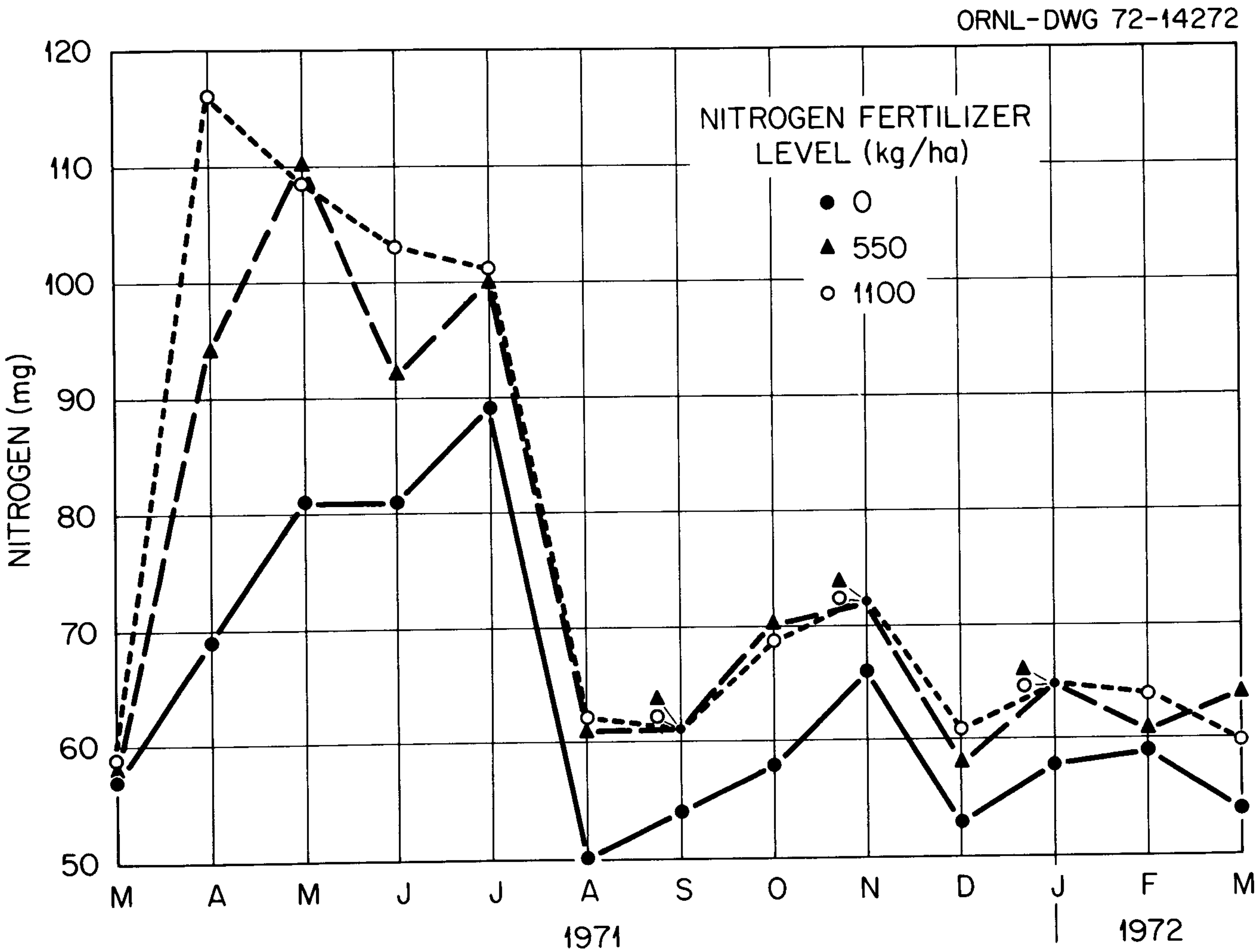

Figure 14. Response of nitrogen in white oak litter bags to the interaction of nitrogen treatments and time. The higher concentration of nitrogen applied at the 1100-kg/ha level enables the microflora to accumulate nitrogen more rapidly thus accounting for the lag in the peak at the 550-kg/ha level. The control response represents the normal accumulation of nitrogen by the microflora.

higher than the 550-kg/ha peak even though twice as much nitrogen was added (Figure 14). The control peak occurred in July and represents the gradual accumulation of nitrogen in the litter during the spring and early summer when environmental conditions are most favorable for microfloral growth.

Unconfined O_1 and O_2 Litter

Nitrogen in unconfined O_1 and O_2 litter. The amount of nitrogen in the unconfined O_1 litter (Table 8) collected at the end of the study does not reflect the influence of fertilizer treatment as much as the O_2 nitrogen content (Table 9). No treatment effect on nitrogen weight could be detected in the O_1 litter, while a significant increase in O_2 nitrogen level occurs due to nitrogen treatment. The failure to detect a significant response in the O_1 was probably because a large portion of the O_1 litter present at the termination of the study fell in the autumn of 1971, after fertilization.

The O_2 nitrogen weights (Table 9) do not consistently reflect the effect of fertilization. This could be due to the large variances associated with O_1 and O_2 samples. Even though the nitrogen weight values are indicative of the fertilization response, a greater number of samples was necessary for full characterization. The O_2 nitrogen concentration values (Table 9) are independent of weight and do reflect a significant difference between untreated plots and those treated with nitrogen. The O_2 segment of the litter merits special attention in future studies of this nature.

Table 8. Concentrations and weights of nitrogen, phosphorus, potassium, calcium, magnesium, and sodium from the unconfined O_1 litter compartment.

Treatment	N	P	K	Ca	Mg	Na
0/0	2.41[a]	0.05	0.07	1.90	0.10	0.01
0/275	2.10	0.05	0.07	1.69	0.12	0.01
0/550	1.80	0.05	0.07	1.91	0.11	0.01
550/0	2.08	0.08	0.07	1.80	0.10	0.01
1100/0	2.00	0.11	0.07	1.77	0.08	0.01
550/275	2.26	0.10	0.08	1.82	0.12	0.01
550/550	2.10	0.19	0.09	1.99	0.12	0.01
1100/275	2.13	0.10	0.07	1.80	0.09	0.01
1100/550	2.37	0.13	0.08	2.03	0.13	0.01
0/0	18,020[b]	370	520	14,210	800	70
0/275	17,300	410	570	13,920	860	80
0/550	14,610	400	560	15,500	640	80
550/0	18,050	690	600	15,620	1040	80
1100/0	15,920	870	550	14,080	890	70
550/275	16,900	740	590	13,610	900	70
550/550	18,980	1710	810	17,980	1090	90
1100/275	14,990	700	490	12,670	690	70
1100/550	16,590	910	560	14,210	870	70

[a] Concentration as a percent of the dry weight.

[b] Milligrams per meter square.

Table 9. Concentrations and weights of nitrogen, phosphorus, potassium, calcium, magnesium, and sodium from the unconfined 0_2 litter compartment.

Treatment	N	P	K	Ca	Mg	Na
0/0	1.21[a]	0.05	0.04	1.93	0.08	0.01
0/275	1.26	0.16	0.05	2.09	0.09	0.01
0/550	1.35	0.33	0.06	2.45	0.07	0.01
550/0	1.46	0.06	0.05	2.13	0.10	0.02
1100/0	1.48	0.05	0.04	2.15	0.09	0.01
550/275	1.58	0.30	0.07	2.42	0.11	0.02
550/550	1.46	0.70	0.07	2.76	0.10	0.02
1100/275	1.62	0.29	0.06	2.37	0.09	0.02
1100/550	1.51	0.42	0.06	2.42	0.11	0.02
0/0	9940[b]	470	400	15,820	950	120
0/275	7950	1030	320	13,170	650	80
0/550	8140	2010	370	14,720	470	80
550/0	7900	320	270	11,510	640	80
1100/0	9710	340	300	14,130	760	80
550/275	8700	1660	380	13,270	660	90
550/550	9390	4530	500	17,720	770	120
1100/275	9920	1810	410	14,550	60.0	110
1100/550	9860	2790	430	15,820	830	110

[a]Concentration as a percent of the dry weight.

[b]Milligrams per meter square.

Soil Solution

Movement of nitrogen in the soil solution. A portion of the nitrogen occurring naturally in the litter or added through fertilization is subject to movement in the soil solution. This nitrogen may be transferred from the litter to the soil exchange complex, or it may be lost from the rooting zone through deep percolation. Most of the nitrogen lost due to leaching is in the form of nitrate (Black 1957, Bear 1964). Another source of nitrogen loss is volatilization. Estimates of volatilization loss from urea run as high as 25% (Allison 1964, Overrein and Moe 1967, Overrein 1969, Ernst and Massey 1960, Gasdorf 1964, Volk 1970, Wahhab *et al*. 1960, Bhure 1970). Nitrogen losses due to leaching and volatilization are controlled by factors such as pH, soil and litter moisture status, cation exchange capacity, precipitation, and urease level (Black 1957, Bear 1964, Volk 1970, du Plessis and Kaontje 1964).

Response of ammonium-N to nitrogen and phosphorus addition. Phosphorus fertilization significantly increased the concentration of ammonium-N in the soil solution. The response means for the 0-, 275-, and 550-kg/ha levels of phosphorus were 20, 23, and 28 μg/ml respectively. The effect of phosphorus on ammonium-N concentration can be seen in the comparison of treatment values for the 0/0, 0/275, and 0/550 treatments (Table 29, Appendix E). The increase in ammonium-N concentration was due to a reduction of soil solution pH at both the 275- and 550-kg/ha phosphorus levels (Table 7, p. 53). Roberge (1972) and Weber and Gainey (1962) noted that when the pH decreased, the amount of soluble ammonium-N increased rapidly. The pH of leachate from the 0/550 treatment declined more and remained lower for a longer period of time than the pH of leachate from the 0/275 treatment. The addition of calcium in the concentrated-superphosphate also may have increased ammonium-N loss through displacement on the soil exchange complex.

As expected, urea application significantly increased ammonium-N concentration in the soil solution from 2 μg/ml at the zero level to 26 and 43 μg/ml at the 550- and 1100-kg/ha levels, respectively (Table 29, Appendix E). The influence of added nitrogen on the ammonium-N concentration of the soil solution can be seen up to one year after fertilization. Both the 550/0 and 1100/0 treatments had returned to near normal levels 9 months after fertilization. Ammonium-N accounted for approximately 50% of the nitrogen loss in the phosphorus-treated plots and 20% of the nitrogen loss in the nitrogen-treated plots. The increased pH associated with urea hydrolysis was responsible for the reduced contribution of ammonium-N during the period immediately after fertilization for three reasons: (1) the elevation in pH reduced ammonium-N solubility, (2) elevated pH created an environment more suitable to nitrifying organisms (Weber and Gainey 1962), and (3) there was an increase in volatilization loss thus reducing ammonium-N concentration in the soil solution. The elevation of ammonium-N and nitrogen concentration probably was due to nitrogen from two sources; that added in fertilizer, and organic material solubilized by the reaction of urea with litter. Considerable amounts of nitrogen were probably sorbed on the surfaces of the solubilized organic particles and/or held within the exchange complex of each particle. Future studies should quantify the contribution of solubilized organic matter to nitrogen loss in soil leachate.

The NP interaction was significant for ammonium-N concentration. The NP interaction means were intermediate to either the nitrogen or phosphorus main treatment means. This differential response was due to the antagonistic effects of nitrogen and phosphorus on microfloral populations and the reduction of nitrogen in solution due to the formation of insoluble compounds such as calcium ammonium phosphate.

Total nitrogen loss in response to fertilization. Cole *et al.* (1961) in a 30-day period recovered 21.50 g/m^2 of nitrogen from a coral soil to which 220 kg/ha of nitrogen had been added. Over a 3-month period approximately 6.00 g/m^2 of nitrogen was leached from a soil treated with 1000 kg/ha of nitrogen (Overrein 1969). Takahashi (1970) found leaching losses of approximately 1.70 and 4.00 g/m^2 from plots treated with 175 and 330 kg/ha of nitrogen fertilizer. The different methodologies used to determine nitrogen loss make direct comparisons with literature values difficult.

The effect of fertilization on total nitrogen loss is summarized in Figure 15. Nitrogen addition increased nitrogen loss in the soil solution, whereas phosphorus addition did not produce significant changes in nitrogen loss. Total nitrogen loss from the 550/0 treatment (45.86 g/m^2) was approximately 83% of the nitrogen added, while the loss from the 1100/0 treatment (84.88 g/m^2) was 76% of the added nitrogen. Isenee and Walsh (1971) found a similar response when more nitrogen loss occurred at the intermediate fertilizer level (224 kg/ha) than at the higher rate

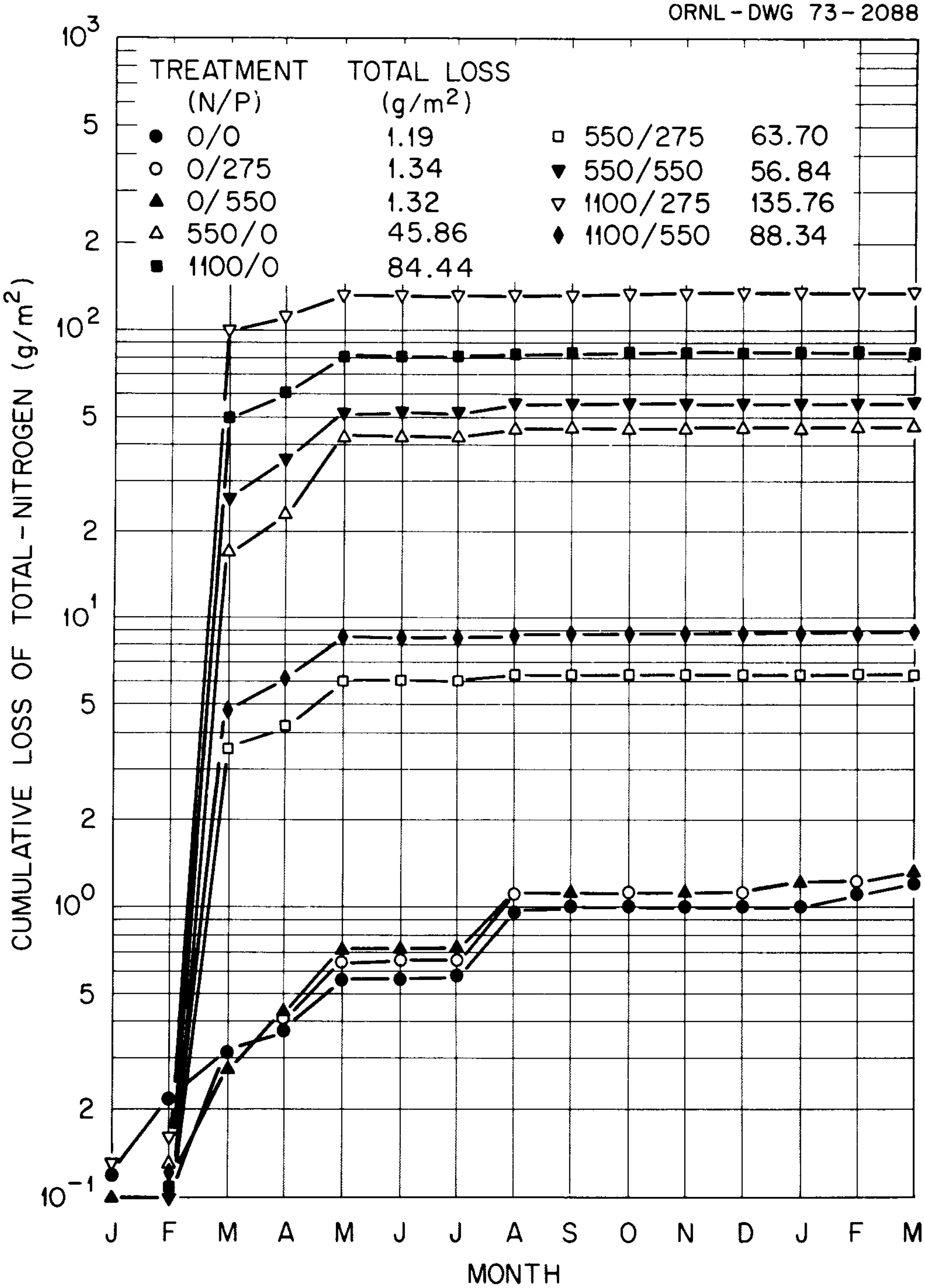

Figure 15. Cumulative total nitrogen loss (g/m^2) from the litter and top 10 cm of the mineral soil in response to fertilizer treatment. The application of nitrogen and phosphorus in a ratio of two to one significantly reduced nitrogen loss.

of addition (672 kg/ha). They attributed this response to differences in the level of nitrification and pH. The same phenomenon appears to have been operative in this study and is substantiated by the pH values and levels of microfloral activity associated with these two treatments (Tables 7, p. 53; 1, p. 21; and 2, p. 25). Nitrogen loss from the litter immediately after fertilization was controlled primarily by chemical phenomena, while biological activity exerts an increasing effect with the passage of time.

When nitrogen level was held constant and phosphorus level increased, more nitrogen was lost at the 275-kg/ha level of phosphorus than at either the 0- or 550-kg/ha levels. This phenomenon can be attributed to the formation of a greater amount of insoluble calcium ammonium phosphate at the 550-kg/ha phosphorus level thus reducing total nitrogen loss (Mees and Tomlinson 1964). At the zero level of phosphorus the pH level immediately after fertilization was greater than at the 275- and 550-kg/ha levels (Table 7, p. 53) thus a greater amount of nitrogen was lost due to volatilization (Mees and Tomlinson 1964). The concentrated superphosphate reduces nitrogen volatilization loss by lowering the pH of hydrolysis, and leaching loss through combination with ammonium in insoluble compounds. This observation could be of considerable significance in formulating fertilizer rates to obtain maximum nitrogen availability with a minimum of nitrogen loss.

VI. PHOSPHORUS

The availability of phosphorus ranks next to nitrogen in importance. Because of its role in structural compounds, nucleic acids, and metabolic reactions phosphorus is an essential constitutent of every living cell (Bear 1964). Phosphorus in the forest soil-litter complex can be divided into two broad categories, organic and inorganic (Black 1957). The principal source of phosphorus is the mineral apatite. Phosphorus may also occur in secondary forms as compounds of calcium, magnesium, iron, and aluminum (Lutz and Chandler 1946). Organic phosphorus compounds are derived from plant and animal residues which contain phytin, phospholipids, nucleoproteins, nucleic acids, and phosphorylated sugars (Bear 1964). Several studies on soil humus summarized by Bear (1964) indicated most organic phosphorus occurs as phytin. The total amount of phosphorus in the soil-litter complex is generally small in comparison to the other macronutrients and may also have a low degree of availability.

White Oak

Phosphorus in white oak litter. The litter is generally considered the primary reservoir of available phosphorus (Lutz and Chandler 1946); therefore any manipulation that alters the rate of mineralization or nutrient status of the litter will in turn affect the amount as well as availability of phosphorus. Consequently, the release of phosphorus from the litter follows quite closely the disappearance of organic material. Comparison of the weight loss curves (Figure 6, p. 35) with those for phosphorus remaining through time (Figure 16) illustrates this relationship. The correlation between phosphorus weight loss and the loss of organic matter was positive, with a correlation coefficient of 0.70. The weight of

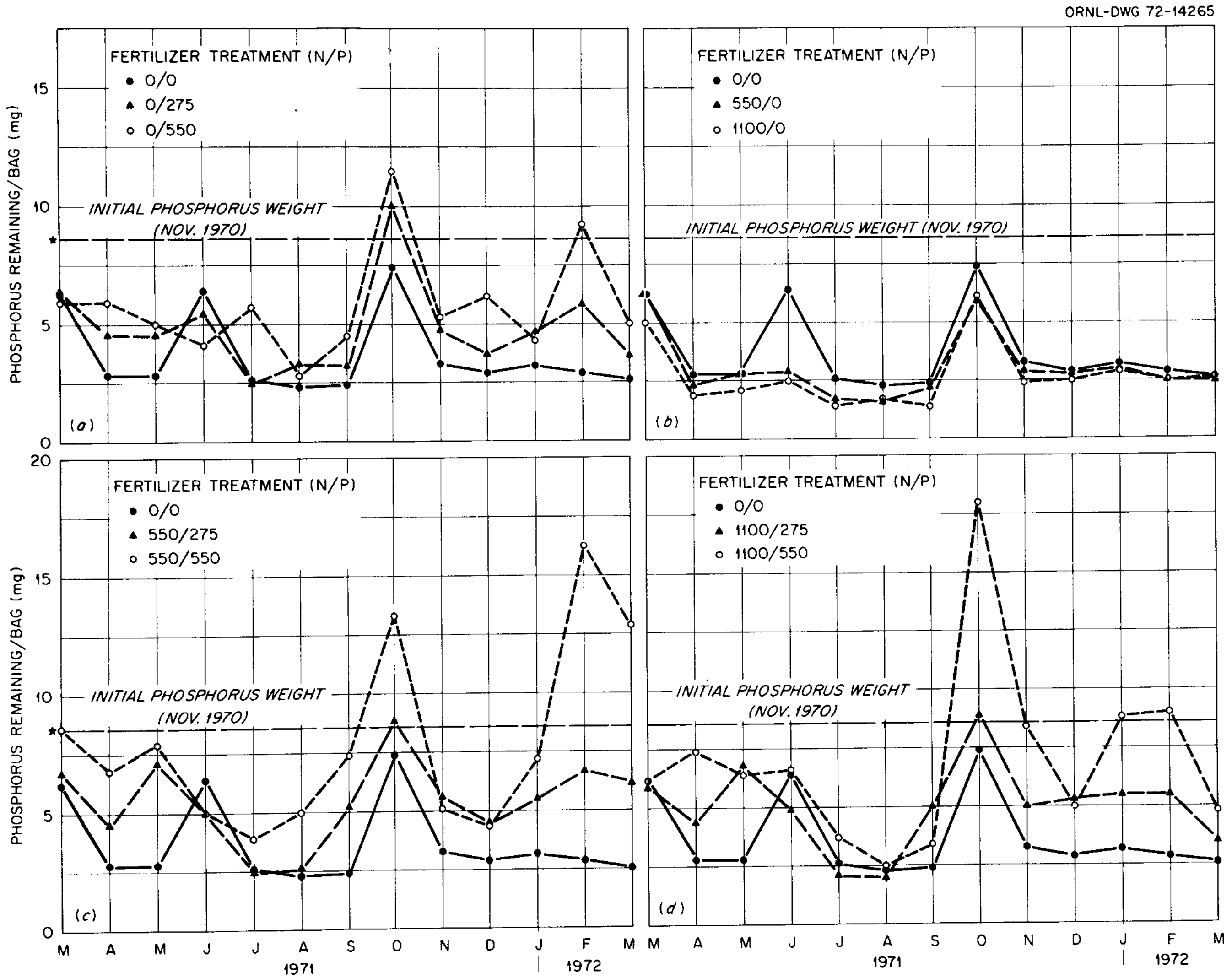

Figure 16. Temporal distribution of phosphorus remaining in white oak litter bags following application of fertilizer treatments. Standard deviations are presented in Table 21, Appendix D. The general decline of phosphorus content of white oak litter bags was positively correlated with the loss of organic material from the litter bags.

phosphorus declined steadily from the time the litter bags were placed in the field until the onset of leaf fall in October. The October phosphorus peak (Figure 16) corresponds with the increase in litter weight (Figure 6, p. 35). Phosphorus concentration increased significantly in October. It would appear that phosphorus leached from the freshly deposited litter was being fixed by the microflora.

Phosphorus fertilizer significantly increased the mean weight of phosphorus from 3.3 mg/bag at the zero level to 5.1 and 6.9 mg/bag at the 275- and 550-kg/ha levels. The effect of added phosphorus on the phosphorus content of white oak litter can be seen in Figure 16a. The weight of phosphorus in the leaves treated with 275 and 550 kg/ha of phosphorus at the zero nitrogen level exhibited a declining trend similar to the control, although the weights were generally higher in treated plots. Alternatively what appeared to be an increase in phosphorus weight attributable to organic sorption could have been the result of a reduced level of decomposition, since weight losses from bags treated with phosphorus at a level other than zero were significantly below the control response (Figure 6, p. 35). Since there was a close parallel between weight loss and phosphorus mineralization, these increases in phosphorus content reflected reduced rates of phosphorus release rather than incorporation of phosphorus. Concentration values substantiate this conclusion (Table 28, Appendix E).

Interaction of phosphorus treatment and time. The response of phosphorus weight to phosphorus treatment differed with the passage of time (Figure 16). This observation was verified statistically by the significant PT interation illustrated in Figure 17. The 0- and 275-kg/ha levels show similar phosphorus patterns throughout the study. The 550-kg/ha level, on the other hand, diverges from this pattern with pronounced peaks in October and February. A similar trend, though not as dramatic as that seen in Figure 17 can be seen in Figure 6a (p. 35). As the inhibitory effect of phosphorus on bacteria diminished, the level of microbial fixation increased since the heretofore relatively undecomposed organic substrate became more suitable for microbial colonization.

Phosphorus response to nitrogen treatment. Nitrogen treatment did not significantly alter the phosphorus content of white oak litter nor was there a significant interaction of nitrogen main treatment with time. This was surprising since nitrogen generally increased weight loss, and greater phosphorus loss would be expected. Apparently, the increased microbial activity associated with the nitrogen addition increased weight loss, but reduced phosphorus loss through fixation. This conclusion is supported by the concentration values which increase as weight loss increases (Table 28, Appendix E).

Numerous studies dealing with phosphorus availability, many of which have been referenced by Black (1957) and Bear (1964), have indicated that pH is of prime importance in controlling the solubilization of phosphorus. A shift from acidic to basic pH values has been found to increase the availability of phosphorus (Bear 1964). Thus, when the pH of the litter was elevated due to urea hydrolysis, it appears that a small portion (statistically insignificant) of the phosphorus

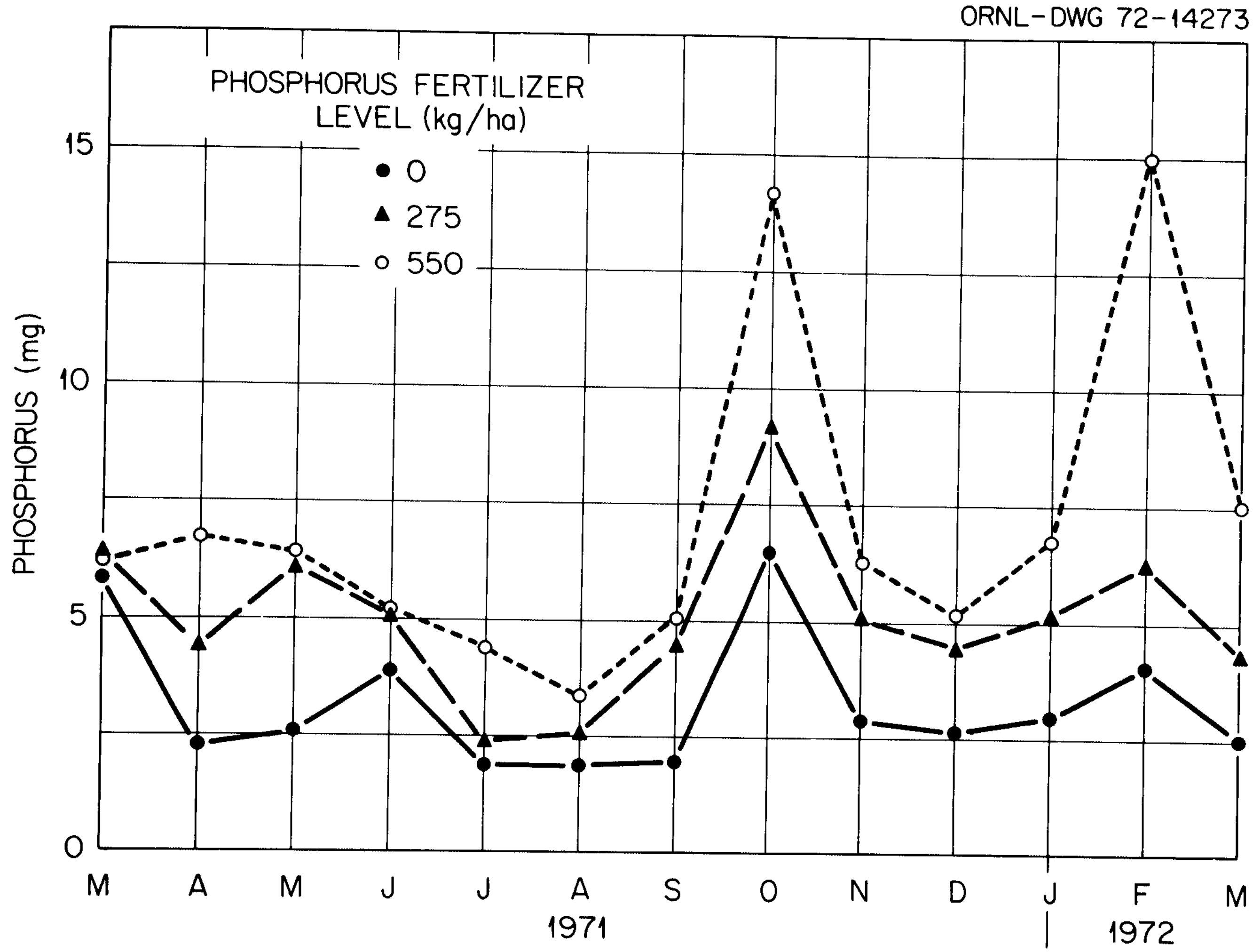

Figure 17. Response of white oak litter bag phosphorus content to the interaction of phosphorus treatments and time. The addition of phosphorus obliterated the normal phosphorus response during the first 3 months after fertilization and then magnified the normal response during the remaining 9 months of the study.

was lost. While weight loss and microbial fixation were the main factors controlling phosphorus dynamics, the likelihood of phosphorus loss due to pH change is supported by soil solution data.

Response of phosphorus to the interaction of nitrogen and phosphorus. When applied alone, phosphorus additions increased the phosphorus content of the litter, while nitrogen reduced the phosphorus content (Figure 18). However, when phosphorus and nitrogen were applied together the phosphorus content increased due to stimulated microfloral activity in response to nitrogen addition. In combination, the added phosphorus retarded the release of naturally occurring phosphorus over the short term, while nitrogen enhanced the fixation of fertilizer phosphorus and thereby increased the amount of phosphorus immobilization over the long term.

Unconfined O_1 and O_2 Litter

Phosphorus in unconfined O_1 and O_2 litter. When the unconfined litter was harvested in March, the phosphorus concentration in the unconfined O_1 ranged from 0.05 to 0.19% (Table 8, p. 63). The amount of phosphorus in the O_1 litter was significantly increased by both the nitrogen and phosphorus main treatment. The same phenomena operative in the white oak litter bags also seem to be operative in the unconfined O_1 litter, except that nitrogen also produced an increase in phosphorus weight because it increased microbial immobilization more than litter weight loss. A significant NP interaction similar to that for the confined white oak litter was also detected.

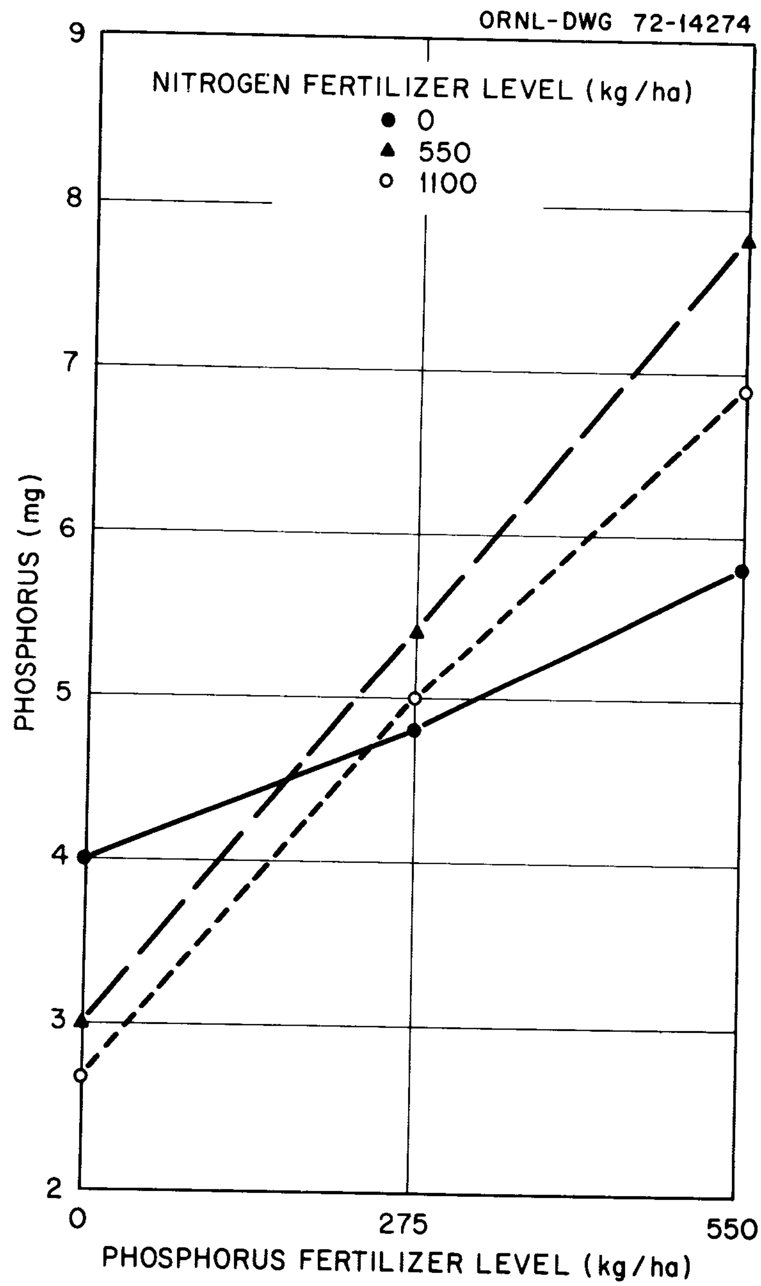

Figure 18. Response of phosphorus in white oak litter bags to the interaction of nitrogen and phosphorus treatments. When applied alone, phosphorus additions increased the phosphorus content of white oak litter, while nitrogen reduced the phosphorus content. When nitrogen and phosphorus were applied together the phosphorus content was increased due to stimulated microfloral fixation in response to nitrogen.

The phosphorus content of unconfined 0_2 litter was significantly increased by phosphorus treatment and reduced by nitrogen treatment. The effect of phosphorus addition can be seen by comparing the 0/275 and 0/550 values with the 550/0 and 1100/0 values (Table 9, p. 64). Phosphorus content of the litter treated with the 550/275 and 1100/275 treatments were quite similar at 1660 and 1810 mg/m^2, while the 550/550 response at 4530 mg/m^2 was twice the 1100/550 response. The mechanism responsible for this response is not clear.

Soil Solution

Movement of phosphorus in the soil solution. A large portion of the phosphorus released by litter decomposition is quickly immobilized by chemical precipitation and microbial immobilization and thus is not lost in the soil leachate (Bengston 1970). Cochran *et al*. (1970) found phoshporus loss in leachate collected from four soils at a depth of 15 cm to range from 0.003 to 0.02 g/m^2. Other estimates of phosphorus loss from the literature were 0.16 g/m^2 from the forest floor and 0.02 g/m^2 from the surface soil (Riekerk 1971). Cole and Gessel (1968) reported 0.08 g/m^2 loss from the forest floor, while Remezov (1961) estimated the loss from an oak forest profile to be approximately 0.003 g/m^2. Due to its high degree of immobility only very small quantities of phosphorus were lost.

Response to phosphorus addition. The addition of phosphorus significantly increased both the concentration and the weight of phosphorus lost in the soil solution. Mean weight loss for the zero phosphorus level was 0.13 g/m^2 compared to 6.98 and 17.84 g/m^2 for the 275- and 550-kg/ha levels. The data suggest that the litter and soil were able to immobilize phosphorus up to a certain level either through microbial fixation or chemical precipitation, but when that level was exceeded the immobilization process became less efficient (Figure 19). This observation is substantiated by the fact that weight loss from the 0/550 was 12 times greater than the loss from the 0/275 treatment. When nitrogen level was held constant at the 1100-kg/ha level and phosphorus increased from 275 to 550 kg/ha, the total loss of phosphorus was equivalent (10.16 vs 10.65 g/m^2). This observation further substantiates the hypothesis that phosphorus and nitrogen were being tied up in insoluble compounds thus reducing total loss at the 550-kg/ha level of phosphorus. Most of the phosphorus appearing in the leachate was probably of fertilizer origin since the addition of phosphorus retarded microfloral activity and reduced the level of microbial fixation as well as the mineralization of naturally occurring phosphorus. The effect of added phosphorus on soil solution phosphorus concentration could be seen even a year after fertilization (Table 28, Appendix E).

Response to nitrogen addition. Nitrogen addition, accompanied by a pH increase of approximately two units (Table 7, p. 53), stimulated microfloral fixation of available phosphorus, resulting in a reduced level of phosphorus loss in the 550/0 and 1100/0 treatments (Figure 19). The findings from this study do not agree with those of Cole *et al.* (1961) and Cole and Gessel (1968), who found an increase from 0.08

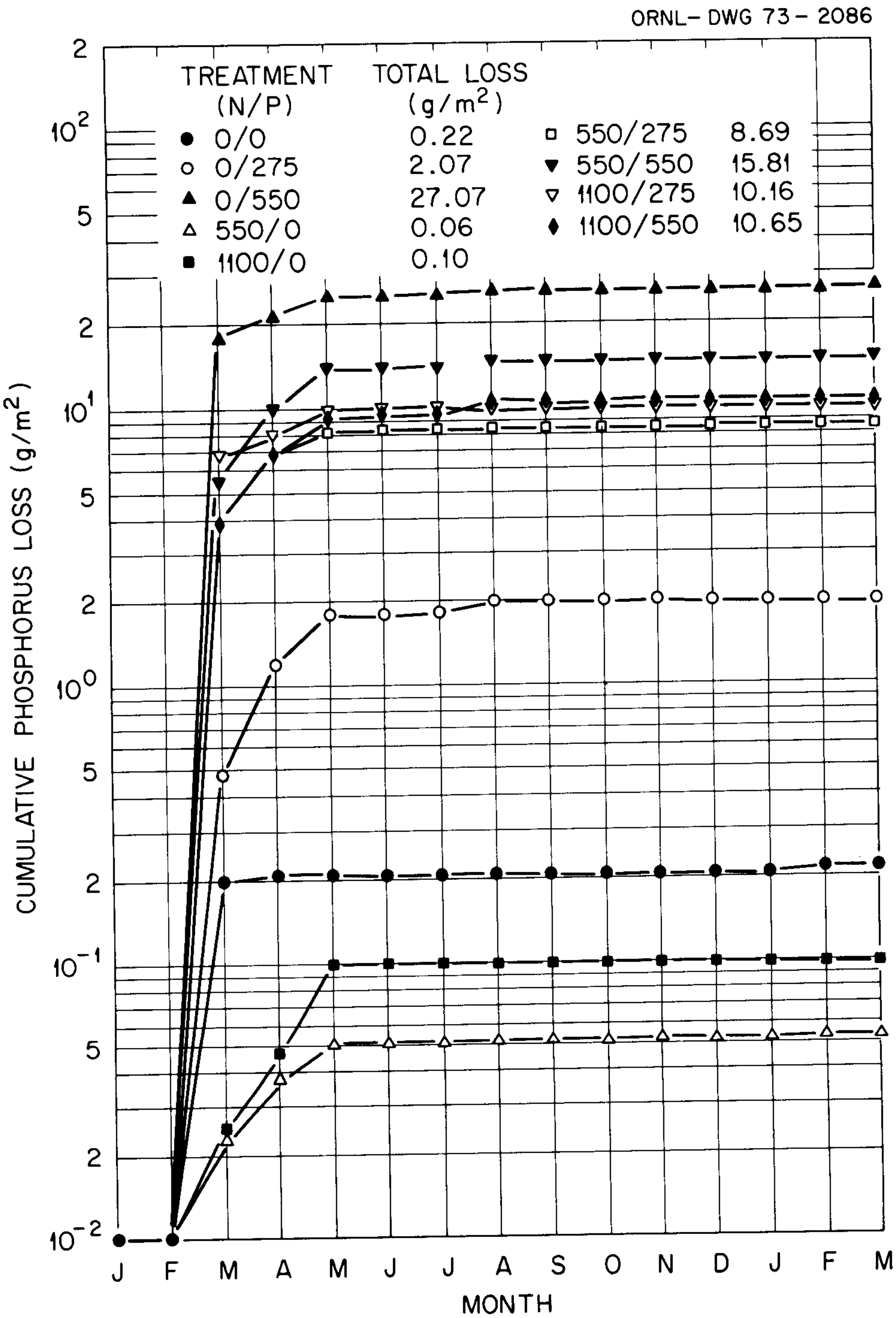

Figure 19. Cumulative phosphorus loss (g/m^2) from the litter and top 10 cm of the mineral soil in response to fertilizer treatment. Nitrogen addition retarded phosphorus loss at the zero level of phosphorus. When nitrogen and phosphorus were applied together at levels other than zero, nitrogen was more effective in retarding phosphorus loss when applied at a ratio of two to one.

to 0.11 and 0.08 to 0.54 g/m^2, respectively, in release of phosphorus to the soil solution following nitrogen fertilization. Although the nitrogen main treatment did not significantly alter phosphorus loss via the soil solution, the 550/0 and 1100/0 losses were certainly different from the 0/0 loss (Figure 19).

Response to the interaction of nitrogen and phosphorus. Phosphorus loss following treatment with both nitrogen and phosphorus was significantly different from the response observed when either element was added alone (Figure 20). Increased increments of phosphorus with no added nitrogen increased phosphorus loss; the magnitude of the loss was much greater after the addition of the second increment of phosphorus than after the third (Figure 20). A mean separation analysis indicated that the losses at the 550/275 and 550/550 levels were not significantly different from the losses at the 1100/275 and 1100/550 levels. This observation indicates that the 1100-kg/ha level of nitrogen was more effective in retarding phosphorus loss at either the 275- or 550-kg/ha level of phosphorus. These data support the hypothesis of nitrogen and phosphorus being tied up in insoluble calcium ammonium phosphate, as well as substantiating the conclusion of Maftoun and Pritchett (1970) that combined nitrogen-phosphorus fertilization reduced the solubilization of phosphorus. This phenomenon appears to be regulated chemically rather than biologically during the period immediately after fertilization.

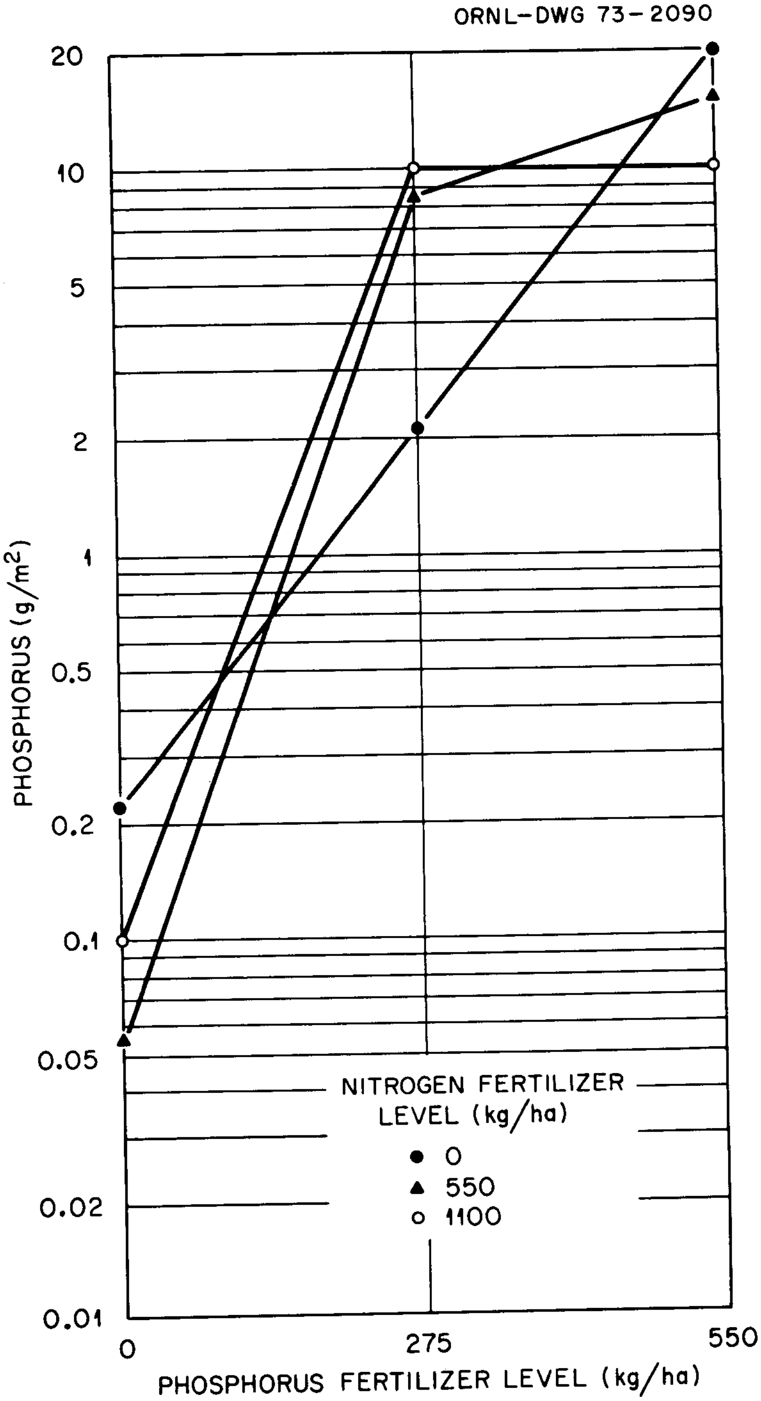

Figure 20. Phosphorus loss from the litter and top 10 cm of the mineral soil in response to the interaction of nitrogen and phosphorus fertilizer treatments. Phosphorus loss at the 550 level of phosphorus addition in the presence of either 550- or 1100-kg/ha of nitrogen was equivalent to the 275 level loss even though twice as much phosphorus was added.

VII. POTASSIUM

There are two sources of potassium in the forest ecosystem: that derived from the weathering of primary and secondary potassium-bearing minerals and that from atmospheric sources (Black 1957, Likens et al. 1967). Potassium mediates certain physiological processes associated with temperature and drought resistance. A large portion (55 to 65%) of the potassium taken up by trees is returned to the litter in leaf fall (Black 1957, Lutz and Chandler 1946). Two processes are responsible for the subsequent mobilization of potassium: microbial decomposition and a shift in exchange complex equilibrium as a result of potassium loss. The susceptibility of potassium to leaching from living and dead organic matter and the soil has been documented by many researchers. A major portion of the literature pertaining to potassium loss from plant material has been summarized by Tukey (1970). Soil losses have been reviewed by Lutz and Chandler (1946), Black (1957), and Bear (1964). Litter and soil pH are not as important in potassium solubilization as in the solubilization of phosphorus. Although pH is of minor importance in potassium solubilization, chemically it can be of great significance from a biological standpoint since microorganisms that liberate potassium are pH sensitive (Bear 1964). Microorganisms also produce acids which are important in the release of insoluble potassium in soil minerals. Microbial immobilization of potassium can shift the equilibrium between available and bound potassium, resulting in the release of bound potassium in order to reestablish equilibrium (Bear 1964).

Most literature estimates of potassium concentration pertain to freshly fallen litter. Consequently, the literature estimates tend to be higher than the levels found in this study. Lunt (1935) reported a decline in potassium concentration of fresh white oak litter from 0.61 to 0.43% in 2 months. Potassium estimates of 0.30% for fresh litter from an oak-hickory forest (Auerbach 1972) are approximately half of the 0.66% potassium concentration observed in this study. Nykvist (1962) and Todd and Cormack (1972) reported even lower values.

White Oak

Response to nitrogen and phosphorus addition. Potassium content of white oak litter exhibited the same general response trend regardless of treatment (Figure 21). Potassium weight in white oak litter bags dropped approximately 45 mg during the first 4 months of the study. During the spring the amount of potassium increased as a result of increased microbial immobilization. Potassium weight dropped during the summer months due to the leaching of potassium from the dead or dying microbes and then increased again in the fall, coincident with the addition of fresh litter to the forest floor. The November peak was due to microbial fixation of potassium leached from the freshly deposited litter overburden. Heavy precipitation in January (Figure 1b, p. 5) again caused the potassium content to drop due to leaching losses. The February increase in potassium was due to increased microbial immobilization.

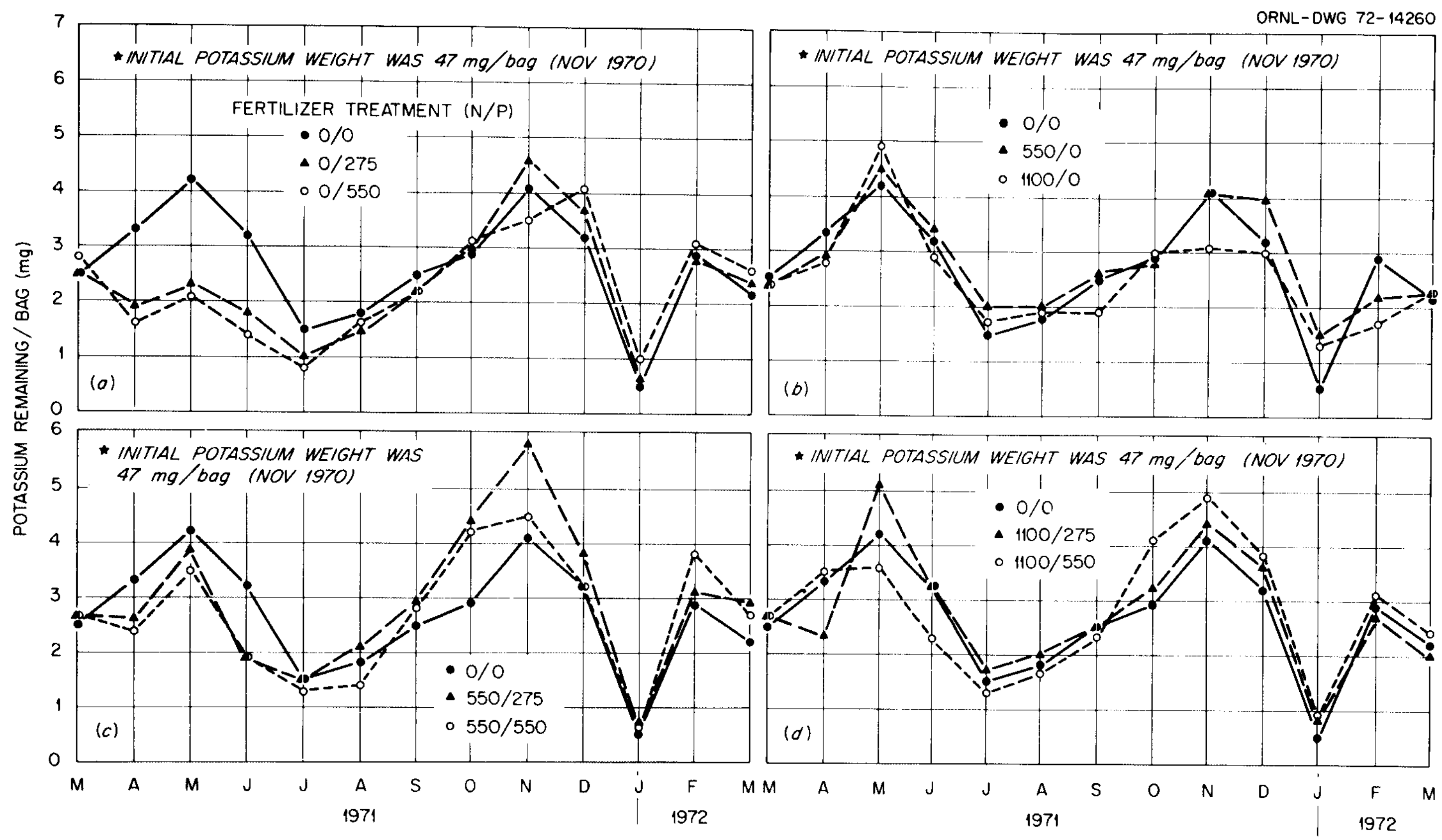

Figure 21. Temporal distribution of potassium remaining in white oak litter bags following application of fertilizer treatments. Standard deviations are presented in Table 21, Appendix D. The response of potassium to fertilization was quite similar to the control response with the exception of the 0/275 and 0/550 treatments where the added phosphorus initially inhibited microfloral fixation.

Phosphorus fertilization did not produce a significant change in the weight of potassium in white oak litter. Potassium loss did not appear to be controlled by microbial immobilization as much as the other elements. Leaching and organic decomposition appear to be of greater importance in controlling potassium loss. It is possible that the reduced level of microbial decomposition associated with phosphorus treatment could have retarded the release of potassium. Comparison of the curves in Figure 21a with those in Figure 21b suggests that microfloral immobilization of potassium was reduced due to inhibition of microfloral populations by phosphorus during the first 4 months after fertilization. Nitrogen offset the effect of phosphorus treatment on potassium loss when nitrogen and phosphorus were applied at rates other than zero (Figure 21).

Interaction of phosphorus treatment and time. Figure 22 summarizes the response of potassium content in white oak litter to phosphorus addition and time. Immediately following fertilization, potassium content at the 275- and 550-kg/ha levels was below the zero level, but with the onset of leaf fall and the associated increase in microbial activity the potassium content in the plots which received either 275 or 550 kg/ha of phosphorus exceeded the zero level response. The inhibitory effect of phosphorus on microbial activity decreased with time thus accounting for the increased weight of potassium.

The interaction of nitrogen treatment and time. Nitrogen treatment interacted with time to modify the potassium response (Figure 23). The differential response of potassium to the 1100-kg/ha nitrogen level

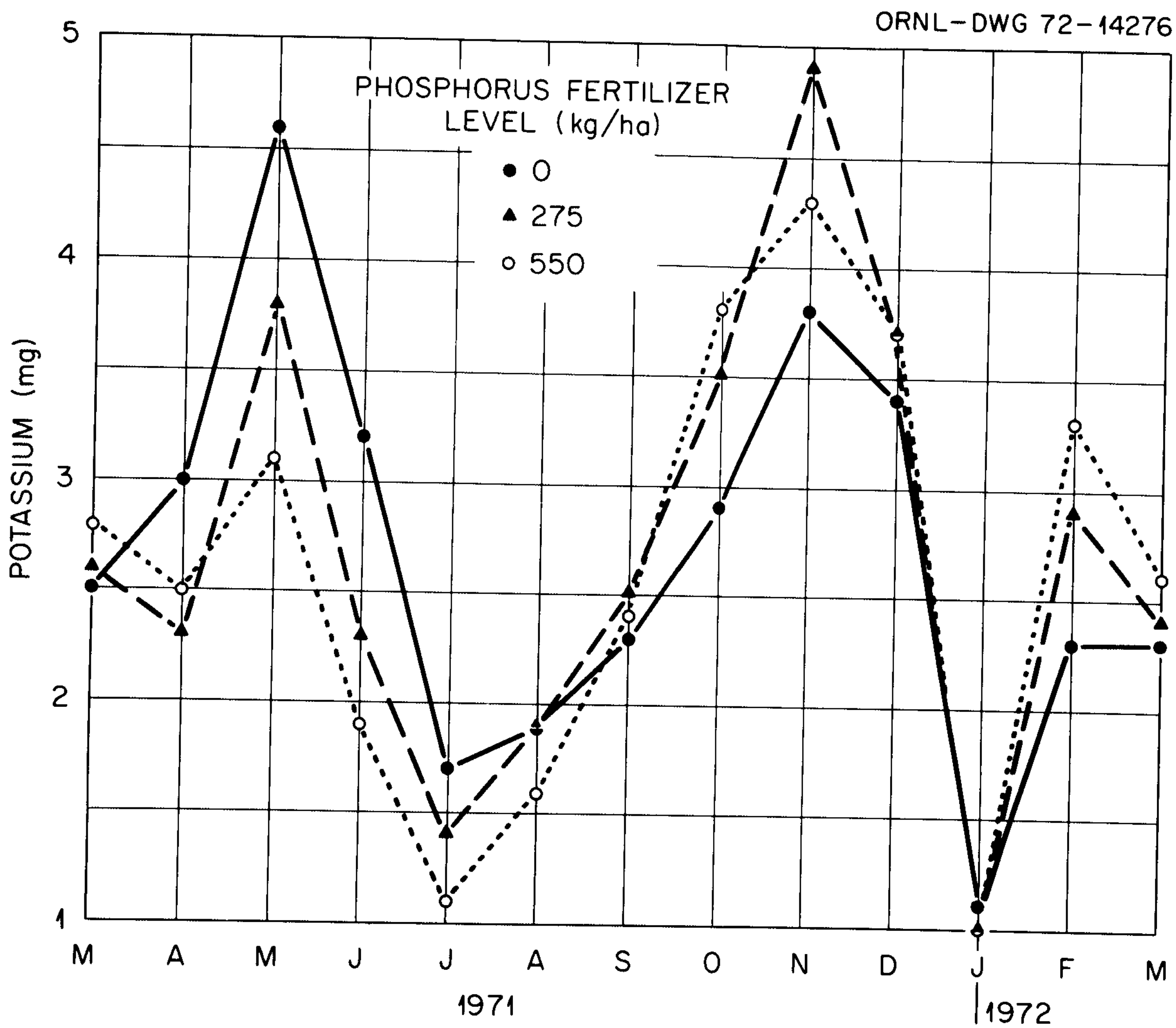

Figure 22. Response of white oak litter bag potassium content to the interaction of phosphorus treatments and time. Phosphorus treatment suppressed the normal potassium response through reduced microfloral fixation during the first 5 months of the study. During the final months of the study the inhibitory effect of phosphorus declined and microfloral fixation increased.

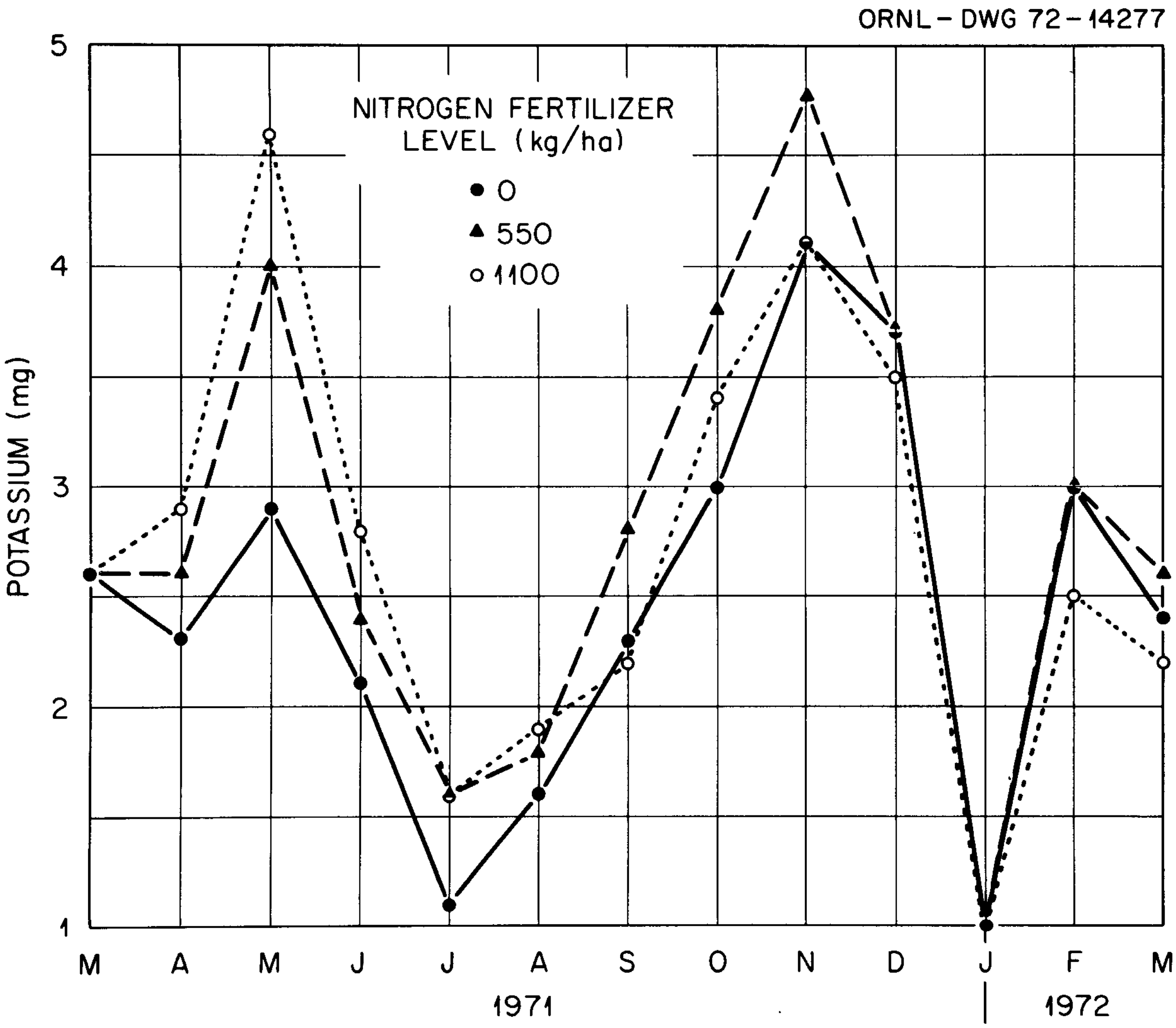

Figure 23. Response of white oak litter bag potassium content to the interaction of nitrogen treatments and time. Greater microfloral fixation occurred at the 1100-kg/ha level during the first 5 months, but thereafter the increased microfloral activity at the 1100-kg/ha level produced a more rapid substrate degradation.

appears to be the prime cause of the significant interaction. Greater microfloral fixation occurred at the 1100-kg/ha level during the first 5 months, but thereafter the increased microbial activity at the 1100-kg/ha level produced a more rapid substrate degradation than at the 0- and 550-kg/ha levels, thus accounting for the reduced level of potassium in the 1100-kg/ha level samples after August. The effect of added nitrogen appears to have lasted at least through the November sample.

The nitrogen-phosphorus interaction. Increasing phosphorus application without nitrogen reduced potassium content while the application of nitrogen without phosphorus did not produce a response significantly different from that at the zero level (Figure 24). Potassium content at the 550/275 level (2.98 mg/bag) was similar to the 550/0 response (2.86 mg/bag), but potassium content of the litter bags dropped to 2.75 mg/bag when the phosphorus level was increased to 550 kg/ha. The mechanism responsible for this reduction was not evident. It could be that the 550-kg/ha level of nitrogen was not able to offset the 550-kg/ha level phosphorus effect on microbial immobilization. This supposition leaves much to be desired since the importance of microfloral immobilization is uncertain. The response of potassium to the 1100/550 treatment supports the hypothesis of offsetting nitrogen-phosphorus responses since the potassium content at the 1100/550 level was greater than at the 550/550 level due to the higher nitrogen addition. The assumption made was that nitrogen stimulated microbial

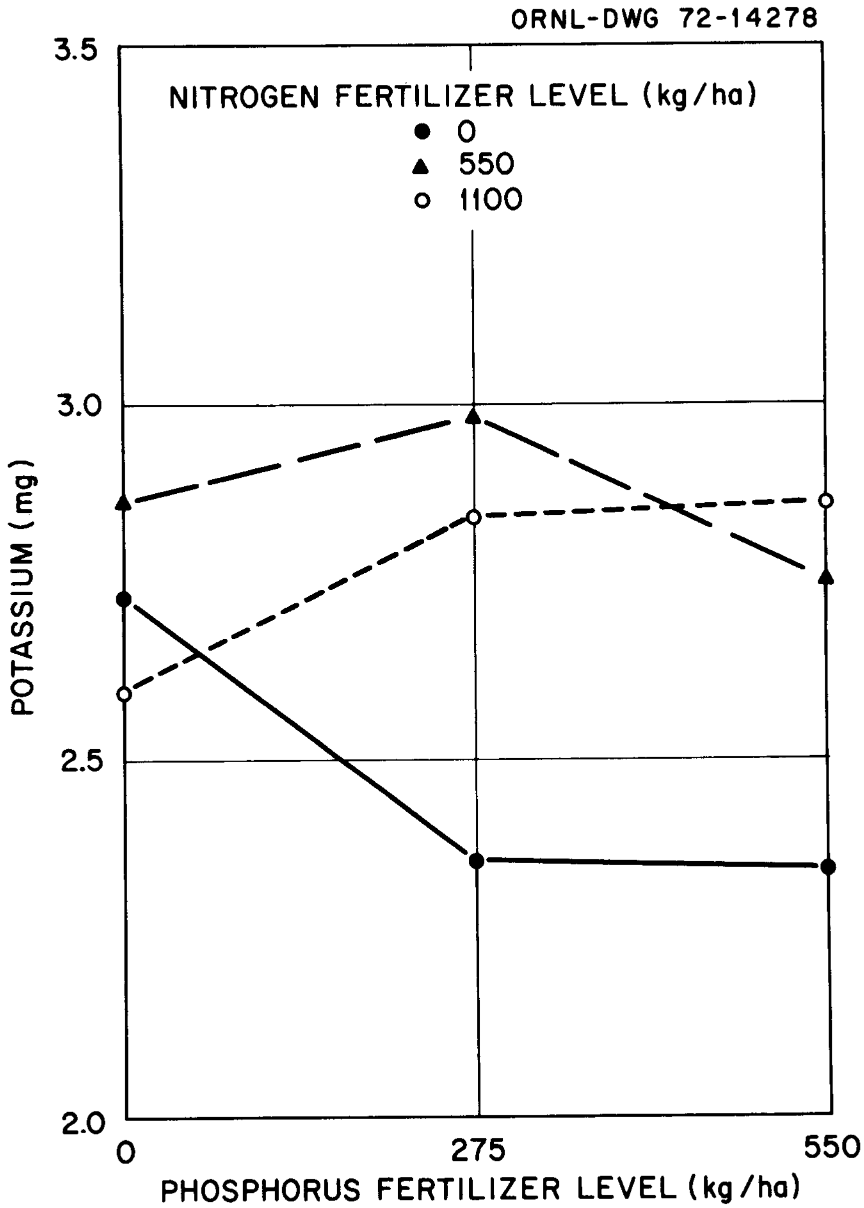

Figure 24. Response of potassium in white oak litter bags to the interaction of nitrogen and phosphorus treatments. Increasing phosphorus application without nitrogen reduced potassium content due to inhibition of microfloral fixation. Combined nitrogen and phosphorus treatment increased microfloral fixation of potassium.

immobilization, but, as previously mentioned, the actual contribution of the microflora was uncertain.

Unconfined O_1 and O_2 Litter

The potassium content of unconfined O_1 litter in control plots (520 mg/m^2) agrees with Henderson's (1972a) estimate of 540 mg/m^2 for chestnut oak dominated sites, while his O_2 litter potassium content at 1540 mg/m^2 was nearly four times the estimate from this study (400 mg/m^2) (Tables 8, p. 63 and 9, p. 64). Analyses of variance conducted on the potassium contents of the O_1 and O_2 litter showed a significant response to both nitrogen and phosphorus. Unfortunately, potassium responses were not consistent within a main treatment; for example, nitrogen both reduced and increased O_1 potassium content.

In an attempt to clarify the response of potassium to nitrogen and phosphorus, a statistical evaluation of the O_1 and O_2 potassium concentration data was conducted. The evaluation revealed that both nitrogen and phosphorus significantly increased the potassium concentration. The increase in potassium concentration due to nitrogen can be attributed to microbial fixation. The mechanism responsible for the potassium increase due to phosphorus is unclear, although it could be related to reduced weight loss, but the data are inconclusive. Consequently, the O_1 and O_2 potassium response is somewhat confused and does little to clarify overall response of potassium to fertilization.

Soil Solution

Potassium movement in the soil solution. Estimates of potassium loss from the litter and mineral soil in the soil solution range from 0.01 g/m^2/year (Remezov 1958) to 3.40 g/m^2/year (Lunt 1935). Intermediate losses have been reported by Cole and Gessel (1968), Riekerk (1971), Cochran et al. (1970), Remezov (1961), Likens et al. (1967, 1970), and Gessel and Cole (1965). Potassium loss from the control was 1.94 g/m^2 over a 65-week period. On an annual basis, this value agrees with literature estimates. However, this value represents potassium movement to a depth of 10 cm, whereas most of the values reported in the literature are for potassium loss in stream flow. Swank and Elwood (1971) estimated potassium loss in stream flow from the Walker Branch Watershed to be 0.40 g/m^2/year, while Best (1971) estimated the combined loss from both litter and soil profile to be 0.50 g/m^2/year. A considerable amount of potassium is intercepted by the soil exchange complex resulting in decreasing potassium concentration in the soil solution with increasing depth (Bear 1964).

Soil solution response to phosphorus addition. Phosphorus treatment significantly increased the potassium concentration in the soil solution (Table 27, Appendix E), but it did not significantly alter the weight of potassium lost from the litter and top 10 cm of the soil. The increase in potassium concentration due to phosphorus treatment could be attributed to reduced microbial fixation or more likely to some chemical phenomena. The failure of phosphorus to modify potassium loss after increasing potassium concentration appears to be an artifact of the method of calculation of potassium loss. The amount of potassium lost as a result of the 0/275 and 0/550 treatments was greater than the 0/0 loss, although the difference was not statistically significant (Figure 25).

Soil solution response to nitrogen addition. The nitrogen main treatment also increased the concentration of potassium in the soil solution but did not increase the amount of potassium lost. The plots treated with nitrogen alone (Figure 25) had potassium losses greater than the control (0/0) loss just as was the case in the plots treated with phosphorus. The higher potassium concentration in the soil solution collected from nitrogen-treated plots could have been due to increased decomposition of organic matter, or displacement on the exchange complex by ammonium. A few studies dealing with the effect of nitrogen on the movement of potassium in the soil solution can be found in the literature. Cole and Gessel (1968) found the loss of potassium (0.54 g/m^2) from the forest floor and rooting zone to be approximately seven times the normal loss after the application of 220 kg/ha of nitrogen from urea and 3.05 g/m^2 after the addition of 220 kg/ha of nitrogen from ammonium sulfate (Cole et al. 1961). Although more nitrogen was added in this study, the range of potassium losses from this study was much less than the range found by Cole (1968).

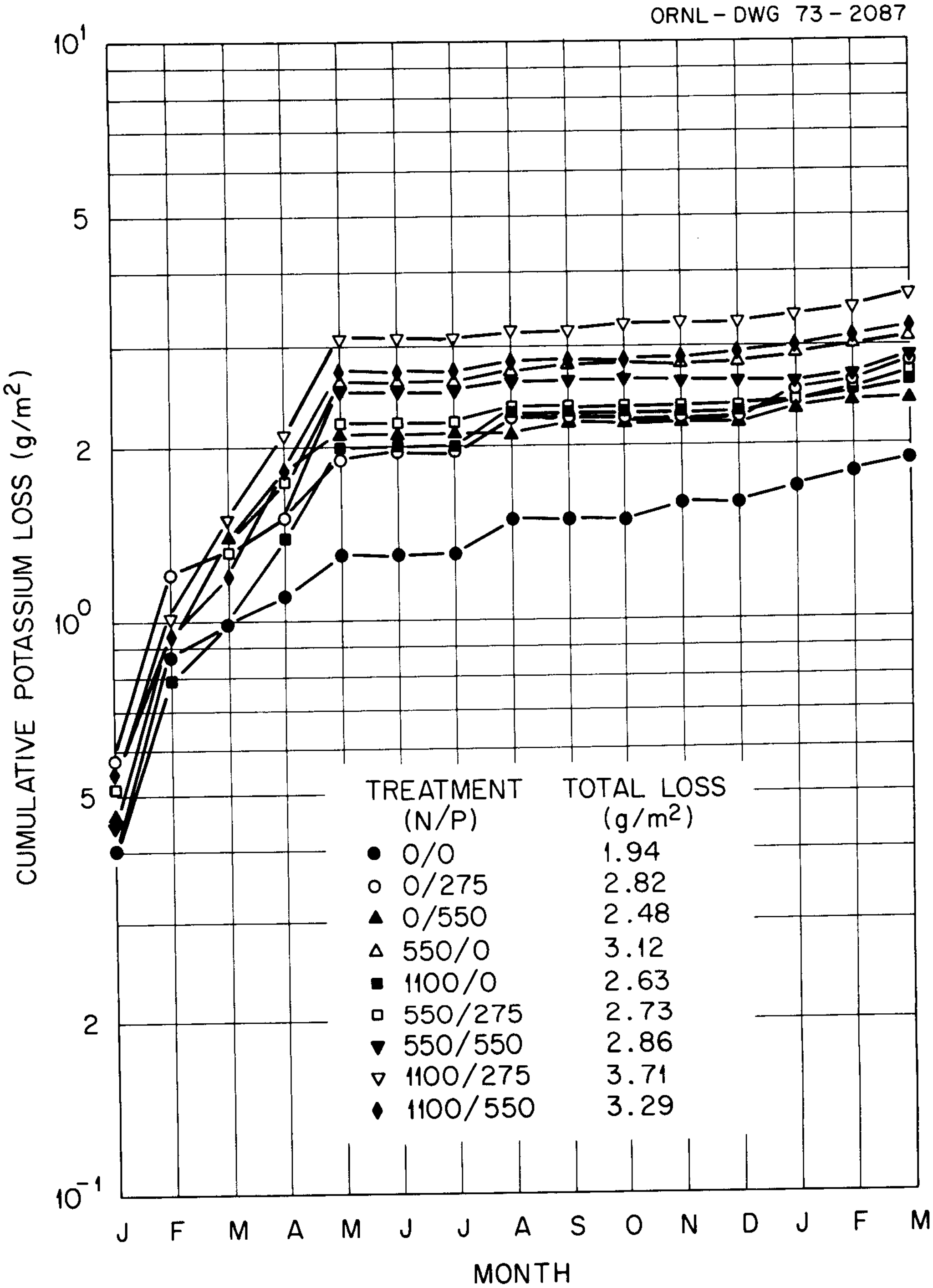

Figure 25. Cumulative potassium loss (g/m^2) from the litter and top 10 cm of the mineral soil in response to fertilizer treatment. Although all fertilizer treatments increased the loss of potassium from the litter and top 10 cm of the mineral soil, the increase was not statistically significant.

VIII. CALCIUM

Calcium is of considerable importance in forest fertility because it influences many physical, chemical, and biological properties of the litter and soil (Lutz and Chandler 1946). The calcium content of the soil can be broken down into three compartments: exchangeable, solution, and nonexchangeable with interchange between all three types (Black 1957). A considerable portion (up to 40%) of the soil calcium is in the exchangeable form and can be lost through ionic substitution and leaching. Calcium is necessary for several biochemical processes in higher plants and is a component of the cell wall (Nason and McElroy 1963). The work of several authors, summarized by Thomas (1969), indicated that calcium can also be present in living leaves in the free ionic form. This partially accounts for the relatively high calcium content of throughfall observed by Best (1971) and others. Stenlid (1958), Mecklenburg and Tukey (1964) and Carlisle _et al_. (1967) suggested that up to 35% of the calcium movement in a forest ecosystem occurs in throughfall and the remainder is released through leaf fall and subsequent litter decomposition. Calcium concentrations in oak litter range from 0.70 to 1.69% (Carlisle _et al_. 1966, Metz 1952).

White Oak

The weight of calcium in white oak litter declined from 109 mg/bag to 37 mg/bag from November 1970 until March 1971. Calcium content increased between the March and April samples to weights generally greater than originally present and remained at that level through the May sample (Figure 26). This increase can be attributed to the spring

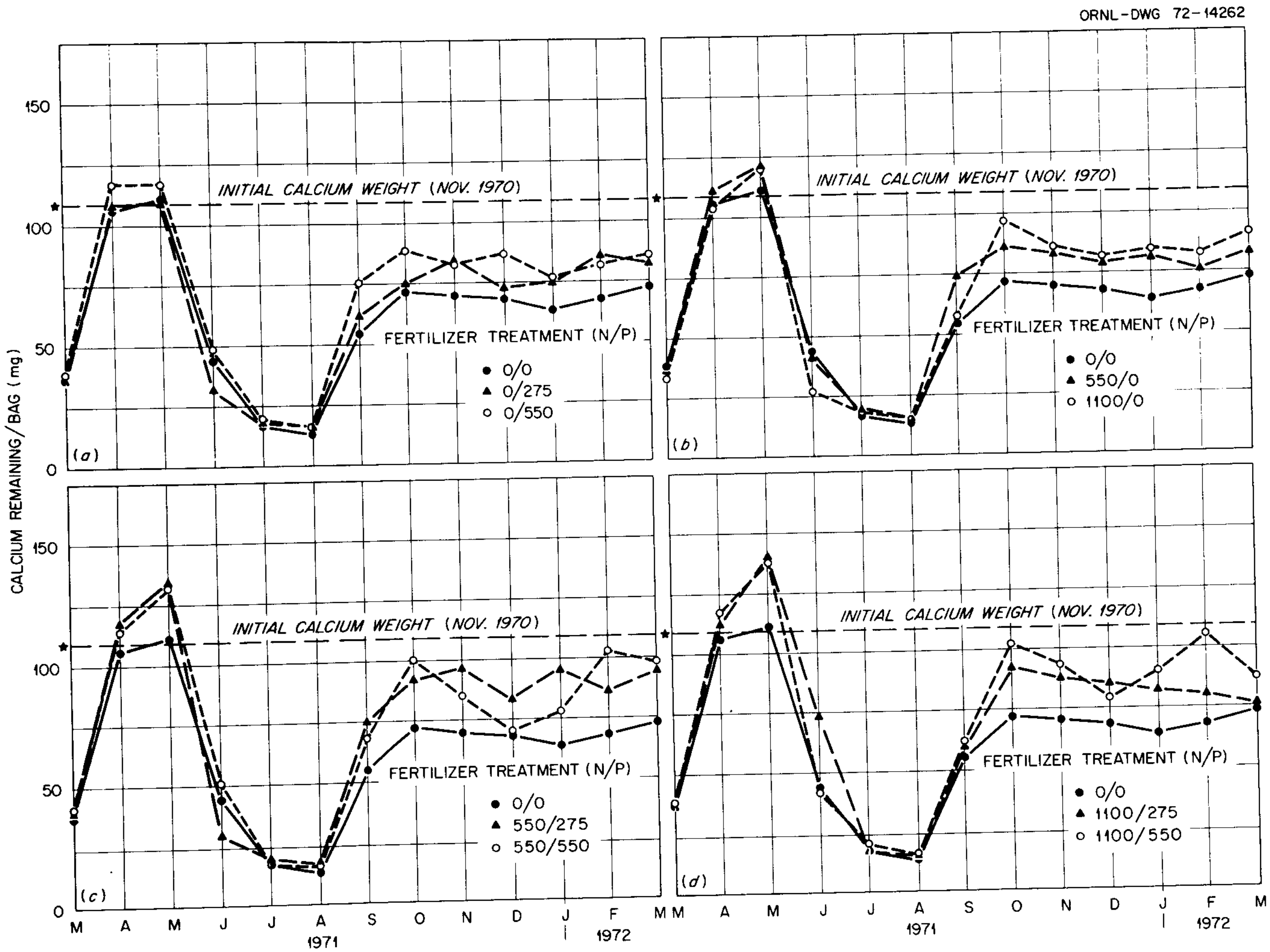

Figure 26. Temporal distribution of calcium remaining in white oak litter bags following application of fertilizer treatments. Standard deviations are presented in Table 21, Appendix D. The addition of both nitrogen and phosphorus increased the calcium content of white oak litter, but different mechanisms were responsible for the responses.

microbial bloom, especially the fungal population. Foster (1949), Witkamp (1971), and Todd and Cromack (1972) reported calcium concentration increases in fungal mycelia to levels higher than those in the substrate. The fungal population counts for April (Table 1, p. 21) verify the increased fungal activity, and visual observations further indicated massive fungal growth.

After the spring peak, calcium content dropped as the microbial population declined. A second increase in calcium content occurred in October in conjunction with leaf fall and the fall microbial bloom and thereafter it remained relatively constant until the end of the study (Figure 26). A positive correlation ($r = 0.86$) was found between calcium weight and total microfloral population. Fungal population alone did not correlate as well as total microfloral population; nevertheless, fungi still seem to be of greater importance than bacteria in immobilizing calcium.

Response to phosphorus addition. The weight and concentration of calcium increased significantly due to the phosphorus addition. This increase may have been due to the calcium in the concentrated superphosphate plus reduced calcium loss due to bacterial inhibition. Inhibition of bacteria was probably not as important as it was for other elements since calcium immobilization by fungi appears to be more important.

Although phosphorus addition significantly increased calcium content, the contribution of fertilizer-derived calcium is uncertain. Comparison of the calcium weight response curves plotted in Figure

26a (calcium added) with the curves in Figure 26b (no calcium added) indicates that both the trends and the magnitudes of the calcium responses were almost identical, thus indicating a lack of microbial immobilization. This would seem to be in accord with the hypothesis that calcium, ammonium, and phosphate were combining to form an insoluble precipitate. If this were the case, then the increase in calcium due to phosphorus treatment would be a result of reduced calcium loss and/or limited microfloral immobilization. Since microfloral activity was limited by phosphorus, the former explanation seems more logical than the latter.

Response to nitrogen addition. Nitrogen addition produced a significant increase in both calcium weight and concentration. Although decomposition increased on the nitrogen-treated plots, the microbial population immobilized more calcium than was mineralized. Increasing calcium concentrations during decomposition were first documented by Lunt (1935) and have since been verified by numerous researchers (Todd and Cromack 1972, Witkamp 1969b, and Thomas 1969).

Interaction of nitrogen treatment and time. Calcium contents at all three levels of nitrogen were about the same during the first 6 months of the study, but thereafter nitrogen addition resulted in calcium contents that were higher than at the zero level (Figure 27). The differential response after leaf fall was probably due to a residual stimulatory effect of the added nitrogen on microfloral immobilization of calcium. A stabilization of the microfloral

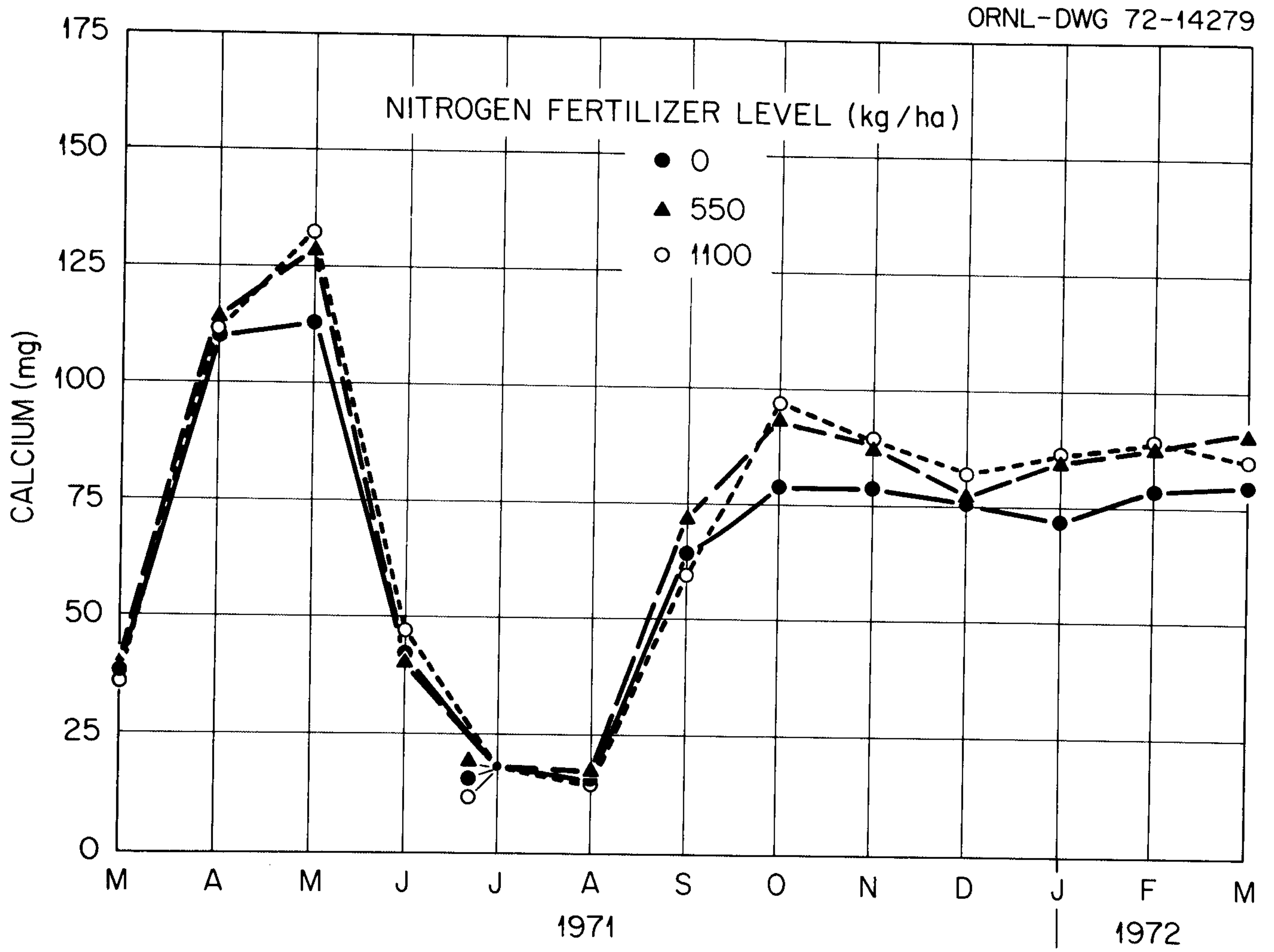

Figure 27. Response of calcium in white oak litter bags to the interaction of nitrogen treatment and time. The differential response with the onset of leaf fall was probably due to a residual stimulatory effect of added nitrogen on microfloral immobilization of calcium.

population could also account for the reduced variation in calcium response observed after the October sample (Figure 27).

Unconfined O_1 and O_2 Litter

Both nitrogen and phosphorus additions significantly increased the calcium content of O_1 litter but for different reasons. Nitrogen stimulated microfloral immobilization in excess of mineralization, while phosphorus retarded mineralization loss of calcium, thus producing an apparent increase. Nitrogen and phosphorus additions significantly reduced the calcium content of the O_2. The chemical reactions associated with urea hydrolysis resulted in considerable calcium loss in solubilized organic matter. The lack of nitrogen prevented the immobilization of calcium even though phosphorus was available for microfloral utilization.

Soil Solution

Calcium movement in the soil solution. According to Likens *et al.* (1970) the concentration of calcium in stream flow from a forested watershed remained constant throughout the year. In other words, calcium was released from the litter, soil, and bedrock at a constant rate. An evaluation of the control calcium concentration data for the soil solution (Table 24, Appendix E) indicates that calcium concentration does remain relatively constant during the year. Total loss of calcium from the control plots was 2.26 g/m^2. Literature estimates of calcium loss in stream flow range from 0.21 g/m^2/year (Remezov 1961) to 10.00 g/m^2/year (Swank and Elwood 1971). Cochran *et al.* (1970) found calcium loss in the soil solution at a depth of 15 cm to range from 2.61 to

21.12 g/m^2/year, while Best (1971) calculated loss from a virgin hardwood stand to be 2.24 g/m^2.

Response to phosphorus addition. Phosphorus addition produced a significant increase in both the concentration and amount of calcium lost in the soil solution. The mean weight of calcium lost at the 550-kg/ha level of phosphorus was approximately twice the loss at the 275-kg/ha level, 13.07 g/m^2 compared to 6.38 g/m^2, which indicates that calcium loss was almost directly proportional to the amount added. However, if calcium loss due to the 0/275 treatment is compared with the 0/550 loss, this relationship is not valid (Figure 28). Calcium loss from the 0/550 (21.16 g/m^2) was 3.9 times greater than the 0/275 loss (5.37 g/m^2). The concentration of calcium in leachate collected from the 0/550 treatment on the first date after fertilization was 15 times greater than the control concentration (Table 24, Appendix E). Within 2 months after fertilization, the calcium concentration in treated plots dropped to 10 to 12 ppm and remained there throughout the study. The large loss following fertilization was due to the leaching of a portion of the calcium added in the concentrated superphosphate. Earlier discussion dealing with calcium in the litter concluded that little of the calcium liberated in the breakdown of the concentrated superphosphate was fixed in the confined white oak litter. Some form of immobilization occurred in the plots receiving the 0/275 treatments since the loss due to the 0/550 treatment was slightly less than four times the 0/275 loss. This response could possibly be explained by a very low level of microbial immobilization in the

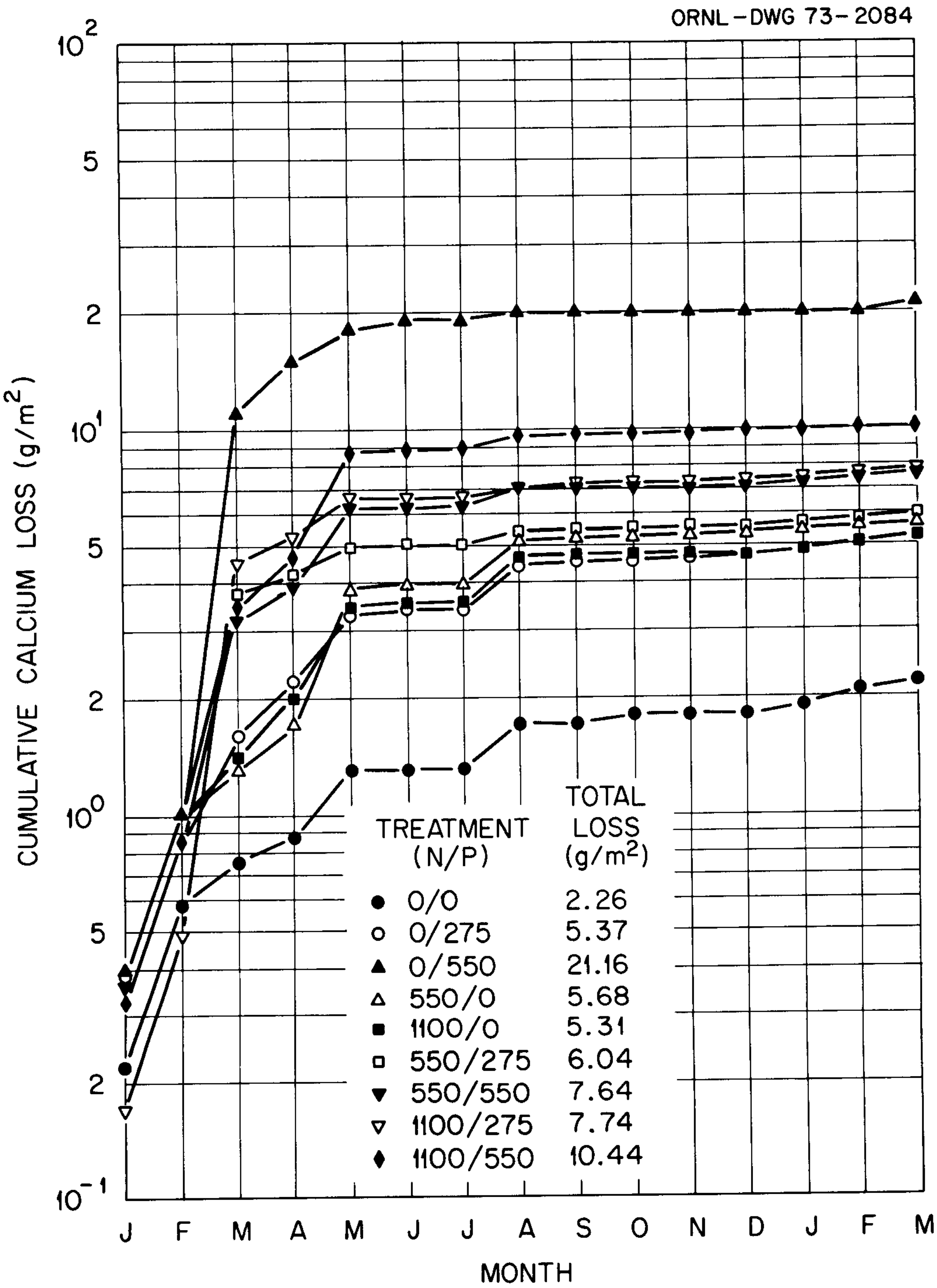

Figure 28. Cumulative calcium loss (g/m^2) from the litter and top 10 cm of the mineral soil in response to fertilizer treatment. The loss of calcium from the litter and top 10 cm of the mineral soil in proportion to the amount added in the concentrated superphosphate was lower at the 550 level of phosphorus in combination with nitrogen, than at the 275 level of phosphorus in combination with nitrogen.

550-kg/ha treated plots due to the inhibitory effect of phosphorus, or the amount of calcium added exceeded the chemical fixation limits of the litter.

Response to nitrogen addition. Nitrogen addition did not significantly alter calcium loss. Calcium losses from the plots receiving 550/0 and 1100/0 treatments were more than twice the control loss (5.68 and 5.31 vs 2.26 g/m^2). The increase in calcium leached from the litter and top 10 cm of the mineral soil after nitrogen fertilization could have been due to an increase in nitrate level as a result of urea hydrolysis, or the replacement of calcium with ammonium. Likens et al. (1970) noted that the soil solution concentration and subsequent loss of calcium increased as the nitrate level increased.

Less calcium was lost at the third level of calcium application, in conjunction with nitrogen than at the second level. This was in agreement with the hypothesis that calcium, ammonium, and phosphorus combined to retard total loss of all three elements. The additional calcium and phosphorus available for combination at the 550-kg/ha level enhanced the loss reduction (Figure 28).

Cole and Gessel (1968) found calcium loss from the litter and rooting zone following application of 220 kg/ha of urea to be 0.89 g/m^2 for a 10-month period, while in another study Cole et al. (1961) found calcium loss to be 48.80 g/m^2 when 220 kg/ha of ammonium sulfate was added. In the latter case, it appears that ammonium replaced calcium on the exchange complex, while the ammonium and nitrate from urea had little effect on calcium loss.

Response to the interaction of nitrogen and phosphorus. The NP interaction term for soil solution calcium loss was significant. A mean separation analysis revealed that the mean response of the 0/550 treatment was responsible for the significant NP interaction (Figure 29). From a comparison of the values presented in Figure 29, it is evident that the proportional loss of calcium was reduced when nitrogen and phosphorus were applied together. The most logical explanation of this phenomenon would be chemical precipitation in conjunction with increased microbial immobilization. Based on the rapidity with which the response occurred, it appears that chemical precipitation is the main factor.

IX. MAGNESIUM

Magnesium in soils is derived from the weathering of primary and secondary minerals (Bear 1964) and from atmospheric sources. Most atmospheric magnesium comes from seawater, although soil dust may also contribute to atmospheric input (Likens et al. 1967). Soil magnesium behaves in the same manner as calcium and occurs in both organic and inorganic form (Lutz and Chandler 1946). Following mineralization magnesium can be absorbed by living organisms, enter the exchange complex, or be lost in soil leachate (Bear 1964). The availability of magnesium to plants is closely related to the calcium and potassium contents of the soil. As the concentration ratio between calcium and potassium narrows, magnesium availability increases.

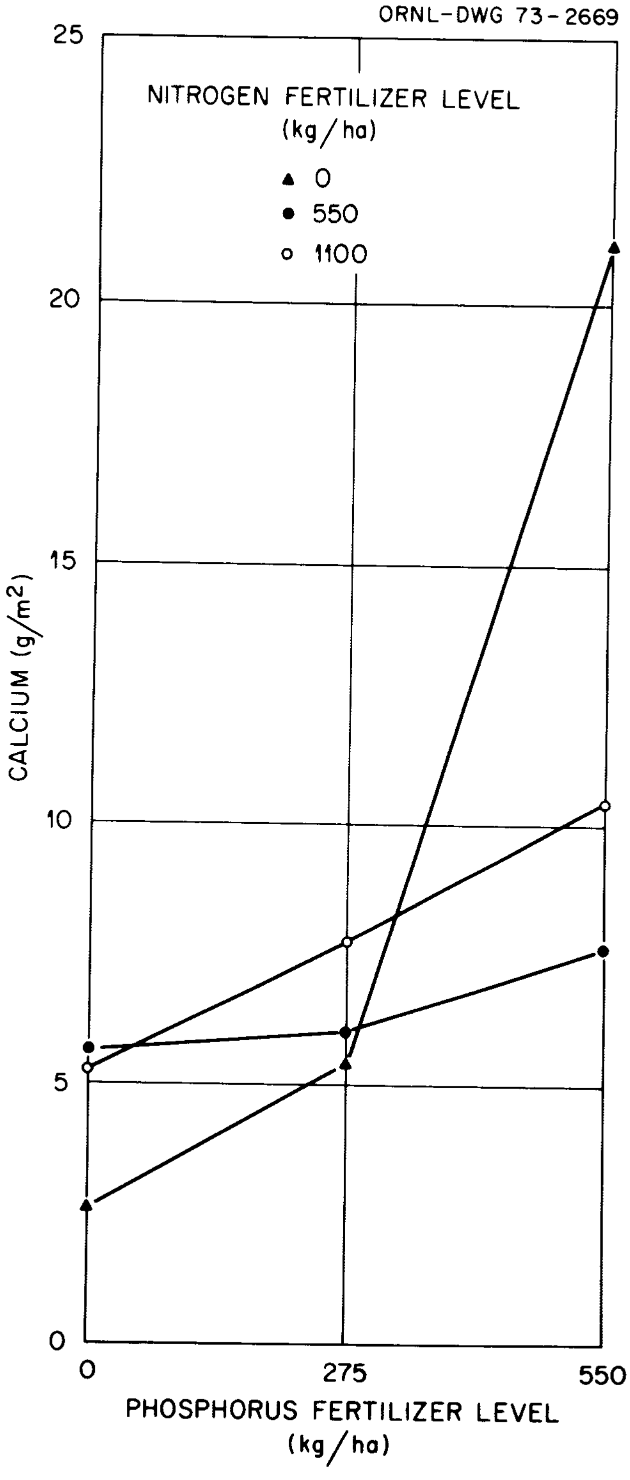

Fig. 29. Response of soil solution calcium loss (g/m^2) to the interaction of nitrogen and phosphorus treatments. Calcium loss was reduced when nitrogen and phosphorus were applied together due to increased microfloral immobilization and chemical precipitation in insoluble calcium ammonium phosphate.

Magnesium incorporated into the chlorophyll molecule accounts for about 3% of the total magnesium content of a plant, while the remainder functions in other physiological processes such as the formation of lecithin and nucleoproteins (Berger and Pratt 1963). Magnesium in the leaves of growing plants is mobile and thus subject to leaching loss. Carlisle _et al_. (167) estimated that leaching accounted for about 69% of the magnesium cycled by forest ecosystems with the remaining 30% returning to the forest floor in litter fall. Magnesium concentration in oak litter ranges from 0.13 to 0.36% (Carlisle _et al_. 1966, Metz 1952).

White Oak

The general response trend of magnesium (Figure 30) was similar to that of calcium (Figure 26, p. 95). Magnesium content declined during the winter of 1970-71 and then increased during the spring microbial bloom, followed by a decline through the summer months, finally increasing with the onset of leaf fall and more favorable moisture conditions. Magnesium level did not decline during the winter of 1971 as it did in the winter of 1970. The mechanism responsible for maintaining the higher level of magnesium is unclear, although it is probably related to either microbial or chemical immobilization.

Response to phosphorus addition. Phosphorus addition at either the 275- or 550-kg/ha level significantly reduced the amount of magnesium in white oak litter bags. The 275-kg/ha and 550-kg/ha responses would seem to indicate that the addition of 275 kg/ha of phosphorus apparently

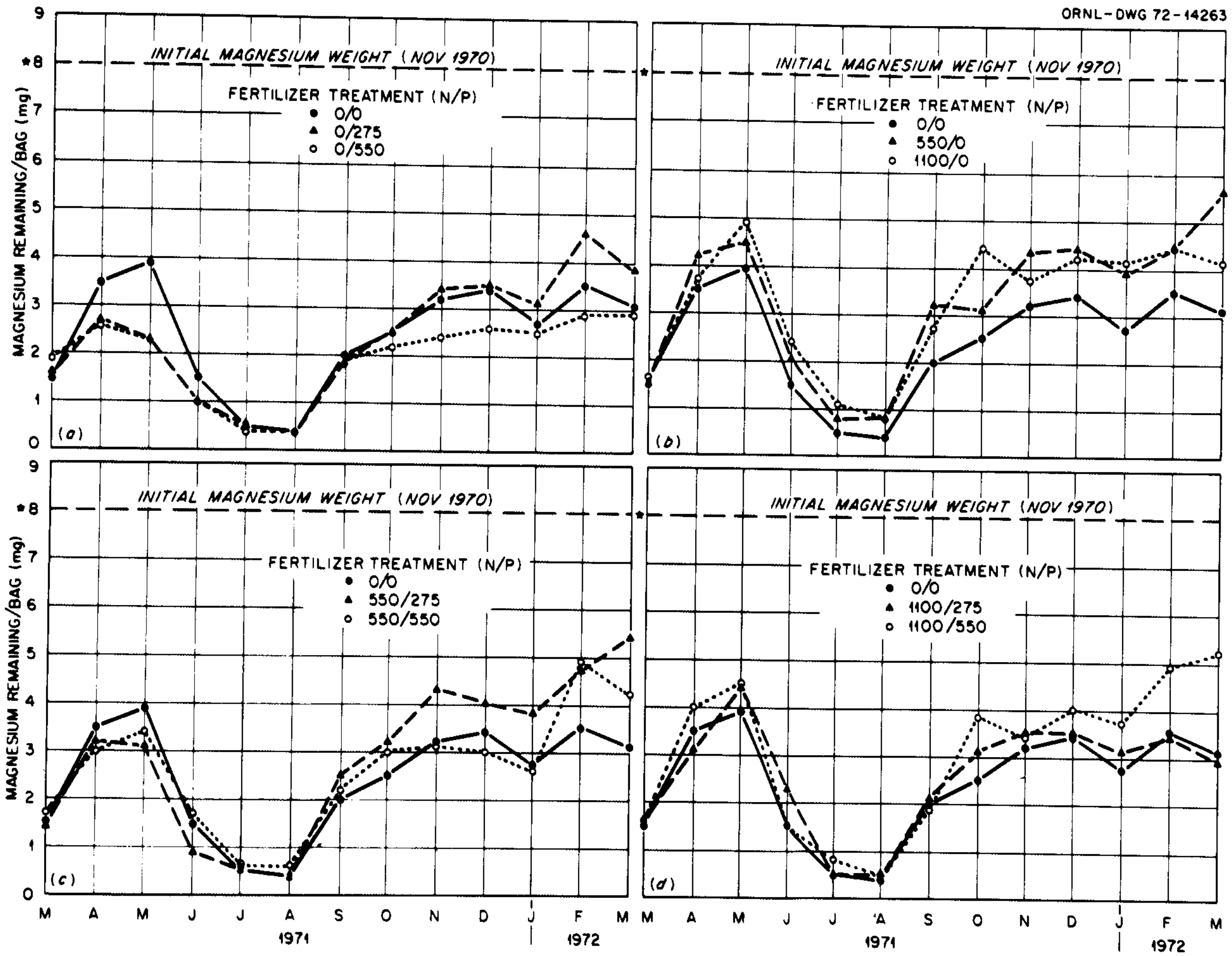

Figure 30. Temporal distribution of magnesium remaining in white oak litter bags following application of fertilizer treatments. Standard deviations are presented in Table 21, Appendix D. Phosphorus addition depressed microfloral fixation of magnesium in white oak litter bags, while nitrogen addition stimulated magnesium fixation.

surpassed some threshold value and that the addition of subsequent increments had no immediate effect.

Interaction of phosphorus treatment and time. The 275- and 550-kg/ha responses were quite comparable until the November sample when the 275-kg/ha level began to behave more like the zero level (Figure 31). The 550-kg/ha treatment did not approach the zero level until February 1972. Thus, the effect of the higher phosphorus addition on microfloral populations lasted 4 months longer than the intermediate addition level and inhibited magnesium immobilization for a longer period of time.

Response to nitrogen addition. Nitrogen addition significantly increased the magnesium content in white oak litter from 2.36 to 2.97 to 3.03 mg/bag. These higher magnesium contents are again attributed to microbial immobilization which could occur especially in the presence of abundant nitrogen (Todd and Cormack 1972). Microbial immobilization appears to be the most logical explanation since the flux of magnesium shown in Figure 30 corresponds with the dynamics of litter bacteria and fungi (Table 1, p. 21). Further, a correlation coefficient of 0.75 exists between magnesium weight and microfloral population level.

Interaction of nitrogen treatment and time. The significant NT interaction appears to be due to a reduction of microbial immobiliz - tion over time due to substrate degradation at the 1100-kg/ha level of nitrogen (Figure 32). The increasing divergence of the zero nitrogen curve from the 550- and 1100-kg/ha curves could be attributed to a lower

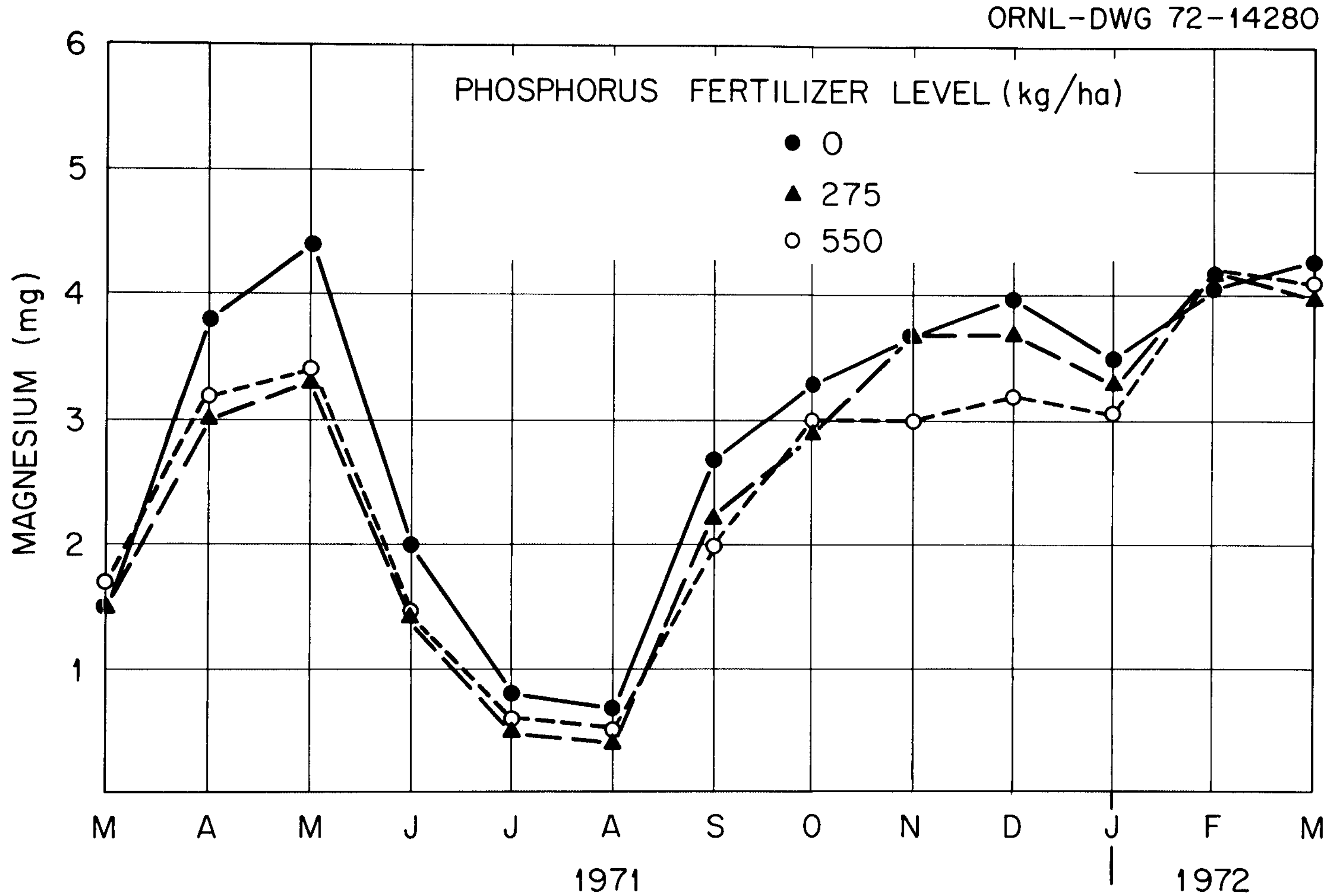

Fig. 31. Response of magnesium in white oak litter bags to the interaction of phosphorus treatment and time. Phosphorus treatment at the 275- and 550-kg/ha levels produced equivalent magnesium responses through the October sample, then the inhibition of microfloral fixation at the 275 level declined to near control level in November, while the 550 level continued to significantly inhibit fixation for the next 3 months.

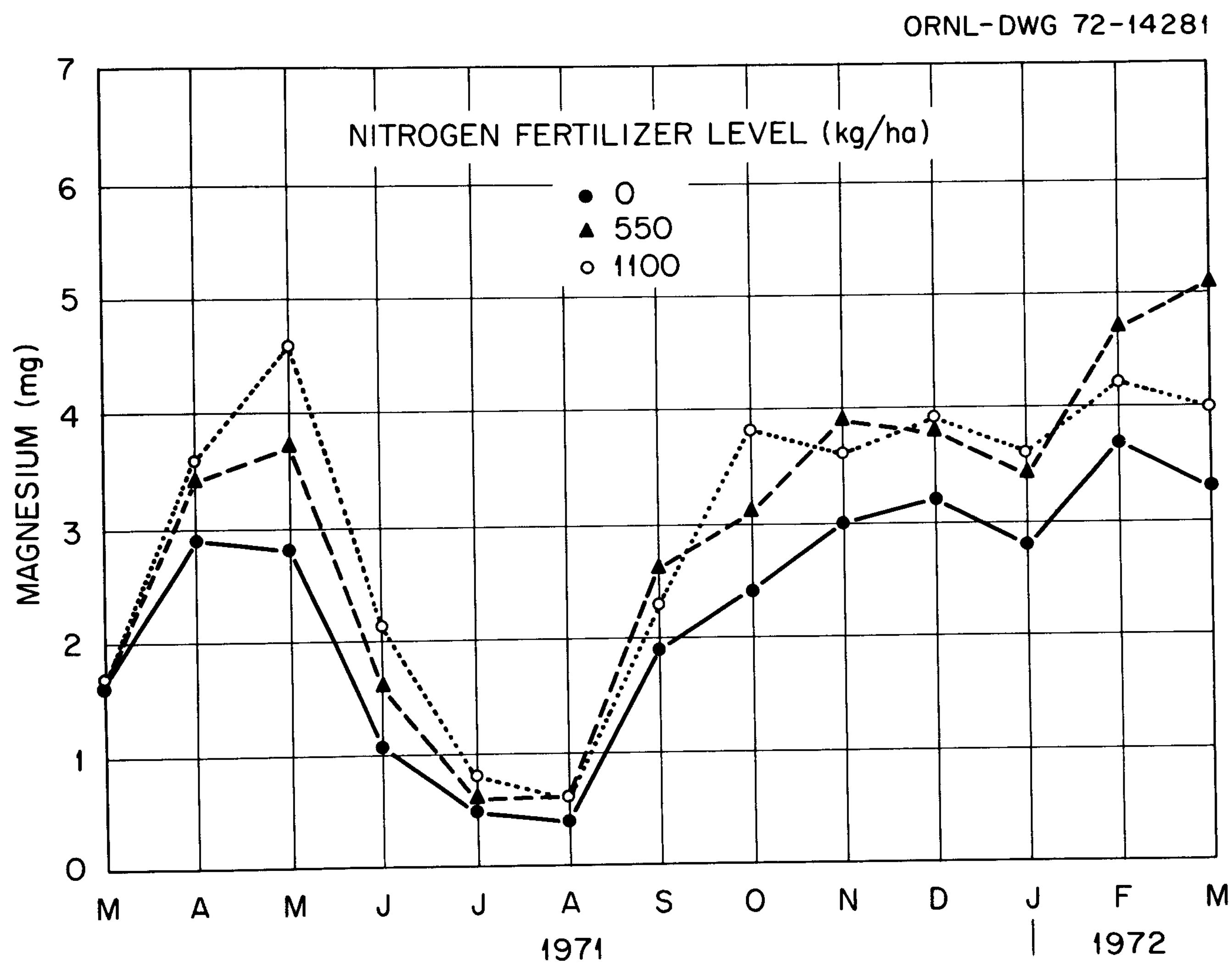

Figure 32. Response of magnesium in white oak litter bags to the interaction of nitrogen treatment and time. Added nitrogen increased microfloral magnesium fixation.

rate of microbial activity, or the 550-kg/ha curve could be diverging due to more favorable nitrogen conditions producing increased immobilization (Figure 32).

The nitrogen-phosphorus interaction. The reaction of magnesium to the 1100/550-kg/ha level of nitrogen and phosphorus appeared to be responsible for the significant NP interaction (Figure 33). Except for the 1100/550 response, magnesium content declined with increasing phosphorus level even in the presence of nitrogen. One possible explanation of this response could be that the phosphorus treatment inhibited decomposition to such an extent that microbial immobilization did not begin to show up until the end of the study. An explanation for the 1100/550 response cannot be offered at this time.

Unconfined O_1 and O_2 Litter

Magnesium content of the unconfined O_1 and O_2 litter was significantly reduced by phosphorus additions. Nitrogen treatment significantly increased magnesium content in the unconfined O_1 litter but did not alter O_2 litter magnesium content. With the exception of the control, the magnesium content of the unconfined O_1 litter was consistently higher than O_2 (Tables 8, p. 63 and 9, p. 64). The lack of a significant nitrogen effect was evident in the reduced magnesium level in the O_2. Evidently nitrogen did not stimulate microbial growth sufficiently to offset the negative effect of phosphorus on microbial populations; consequently, less magnesium was immobilized in the O_2. Although the analysis of variance indicated that phosphorus

ORNL-DWG 72-14282

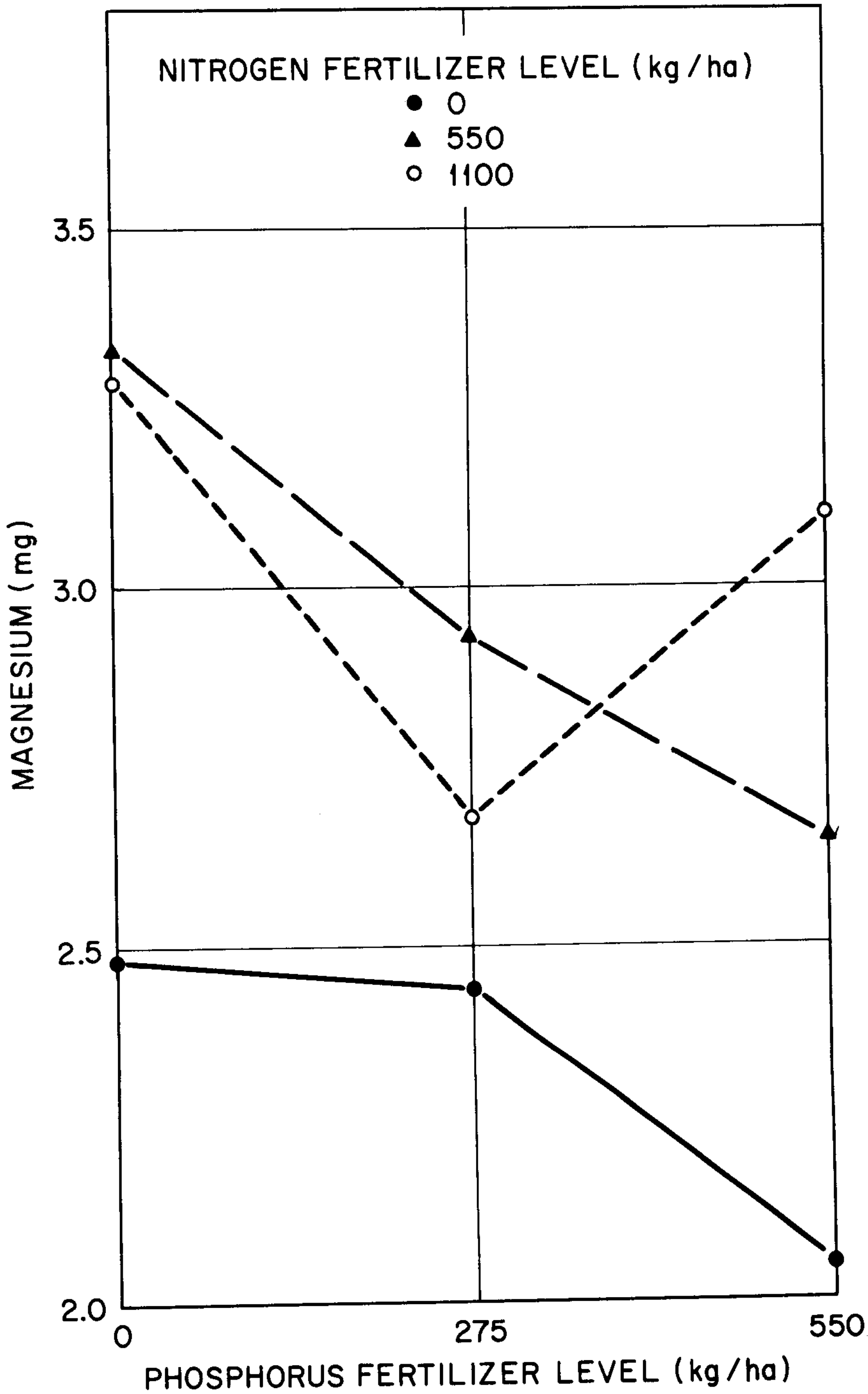

Figure 33. Response of magnesium in white oak litter bags to the interaction of nitrogen and phosphorus treatments. Increasing phosphorus level even in the presence of nitrogen reduced microfloral immobilization of magnesium.

reduced magnesium content; when phosphorus and nitrogen were applied together, the magnesium level increased with increasing phosphorus (Tables 8, p. 63 and 9, p. 64). This seems to indicate that adequate amounts of both nitrogen and phosphorus were necessary for microbial immobilization of magnesium.

Soil Solution

Magnesium movement in the soil solution. Likens *et al*. (1970) reported that magmesium concentration in stream flow remained constant throughout the year. The output of magnesium in stream flow is correlated with the magnesium level of the bedrock. Magnesium losses in stream flow from Coweeta, Hubbard Brook, and Walker Branch (0.31, 0.25, and 5.05 g/m^2 respectively) show a considerable degree of difference, which can be attributed to the magnesium-rich dolomitic limestone underlying Walker Branch (Swank and Elwood 1971). Magnesium in soil leachate as determined by Cochran *et al*. (1970) was 0.18 g/m^2/year, while Best (1971) estimated magnesium loss from deciduous litter to be 0.53 g/m^2/year and soil loss to be 0.05 g/m^2/year.

Effect of phosphorus addition. Phosphorus addition significantly increased the magnesium concentration of the soil solution. The reduction in microbial activity associated with phosphorus treatment appears to have been responsible for the increased concentration due to reduced microbial immobilization. This appears to be a questionable explanation due to the rather large increase in magnesium concentration at the first collection after fertilization (Table 26, Appendix E).

The rapid increase in magnesium after fertilization could have been the result of calcium replacement of magnesium on the exchange complex. Both of these hypotheses have merit, but the latter seems to be the most likely explanation due to the rapidity of the response.

The increase in magnesium concentration due to phosphorus treatment resulted in a significant increase in the weight of magnesium lost in the soil solution. Magnesium loss nearly doubled when phosphorus application was increased from 275 to 550 kg/ha (1.60 to 3.00 g/m^2). This response, as hypothesized previously, appears to be chemically rather than biologically controlled. The same relationship held true when phosphorus was applied in conjunction with nitrogen. The application of nitrogen without phosphorus produced a decrease in magnesium loss with increasing nitrogen level (Figure 34). This would seem to indicate that nitrogen retarded magnesium loss slightly through stimulation of microbial immobilization (nitrogen addition did not significantly alter magnesium loss), while phosphorus addition increased loss by replacing the magnesium on the exchange complex with calcium from the concentrated superphosphate molecule.

X. SODIUM

Sodium in forest litter normally exhibits the same general characteristics as potassium, calcium, and magnesium, although it is present in much smaller quantities (Scott 1955). The sodium concentration in litter generally falls within the 0.01 to 0.06% range (Scott 1955). The sodium concentration in oak litter is generally higher than most other species and was found to be 0.01% by Ovington

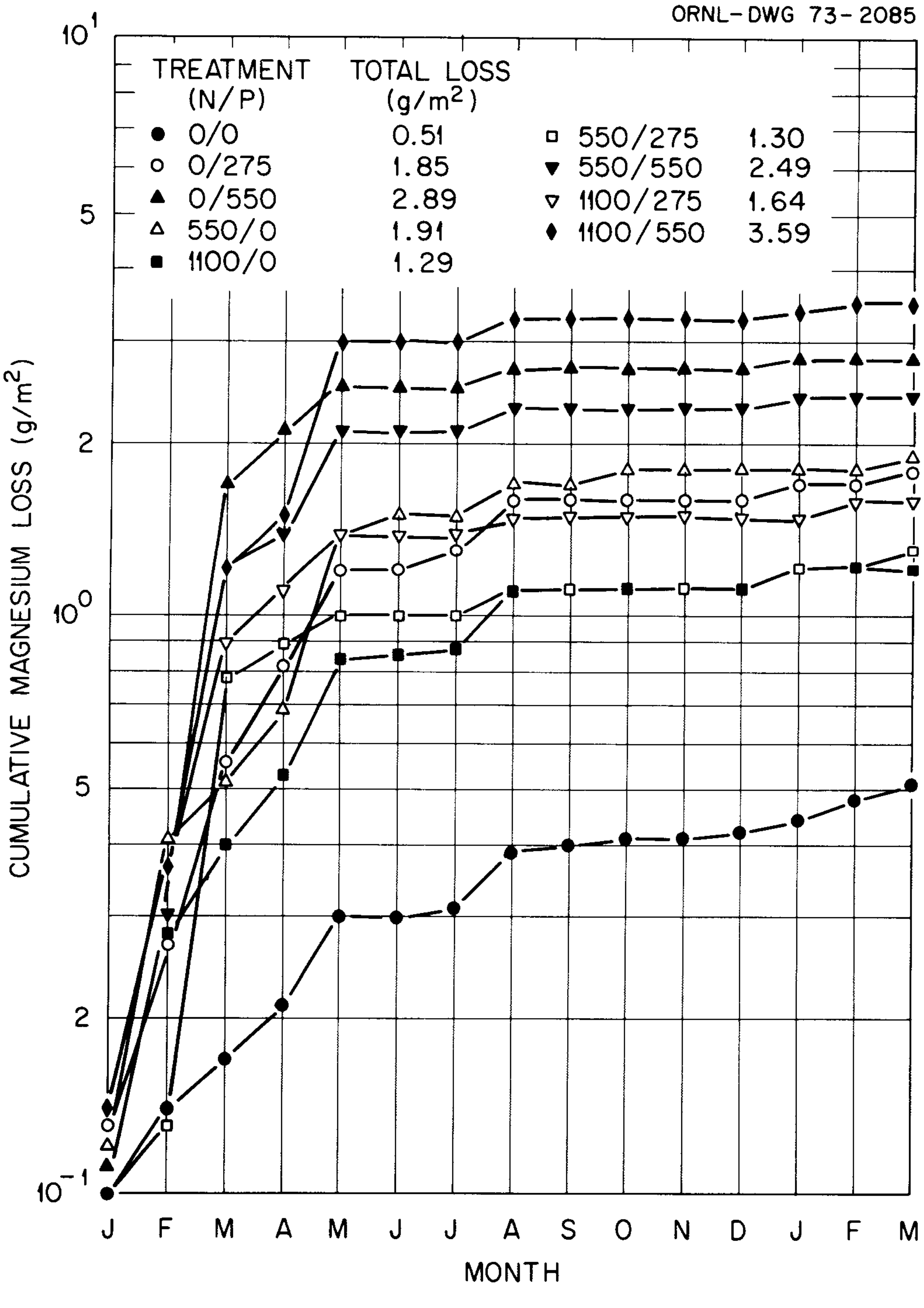

Figure 34. Cumulative magnesium loss (g/m^2) from the litter and top 10 cm of the mineral soil in response to fertilizer treatment. Increasing phosphorus level significantly increased magnesium loss as illustrated by the two groupings of curves in this figure.

(1960). Sodium, like calcium and magnesium, is derived from the weathering of residual material and from atmospheric input. The pattern of sodium input from the atmosphere corresponds closely with rainfall amounts (Best 1971). Ocean spray and soil dust are thought to be the principal sources of atmospheric sodium (Likens et al. 1970). The amount of sodium utilized by plants is small and, although its function has not been well defined, it appears to be able to substitute for or interact with potassium, calcium, and magnesium (Black 1957).

Sodium is one of the most loosely held metallic ions and is readily lost in the soil leachate (Tisdale and Nelson 1966). Sodium apparently substitutes for some of the calcium and magnesium that would accompany anions lost in percolating waters. Stream discharge of sodium follows the same pattern as stream discharge of water. Small increases of sodium in stream flow occur during the fall and winter months due to leaching of sodium from freshly fallen litter and increased surface erosion. Although sodium flux is presently of little interest, it is better to know in advance what the response of sodium to fertilizer might be.

High variability appears to be an inherent characteristic of sodium determinations. Due to the small concentration of sodium in leaf litter, it is quite possible for analytical error to occur either in sample preparation or chemical analysis. Sodium contamination due to handling probably accounts for a major portion of the variability associated with the sodium determinations.

White Oak and Unconfined O_1 and O_2 Litter

Response to fertilizer treatment. It is difficult to discern any consistent response pattern from the values plotted in Figure 35 other than a general decrease in sodium weight from March through August and a slight increasing trend after leaf fall. The decline in sodium weight during the first half of the study can be attributed to leaching loss, while the fall increase was due to immoblization of sodium leached from freshly fallen litter. Both nitrogen and phosphorus main treatments significantly increased the sodium content of white oak litter bags but for different reasons. The response of sodium to phosphorus appears to be geared to the effect that phosphorus has on decomposition, in that as the level of decomposition dropped the sodium content of the litter bags increased. The reduced decomposition level limited the mineralization and subsequent leaching of sodium. Nitrogen treatment, due to its stimulatory effect on the microflora probably increased the level of sodium immobilization by the microflora. Neither nitrogen nor phosphorus interacted with time to affect the observed sodium response. Nitrogen addition reduced O_1 and O_2 litter sodium content (Tables 8, p. 63 and 9, p. 64). The O_2 exhibited a wider range of response than did the O_1. Phosphorus additions did not alter O_1 litter sodium but reduced sodium content in the O_2. The greater loss of sodium in the O_2 was probably associated with the solubilization of organic matter.

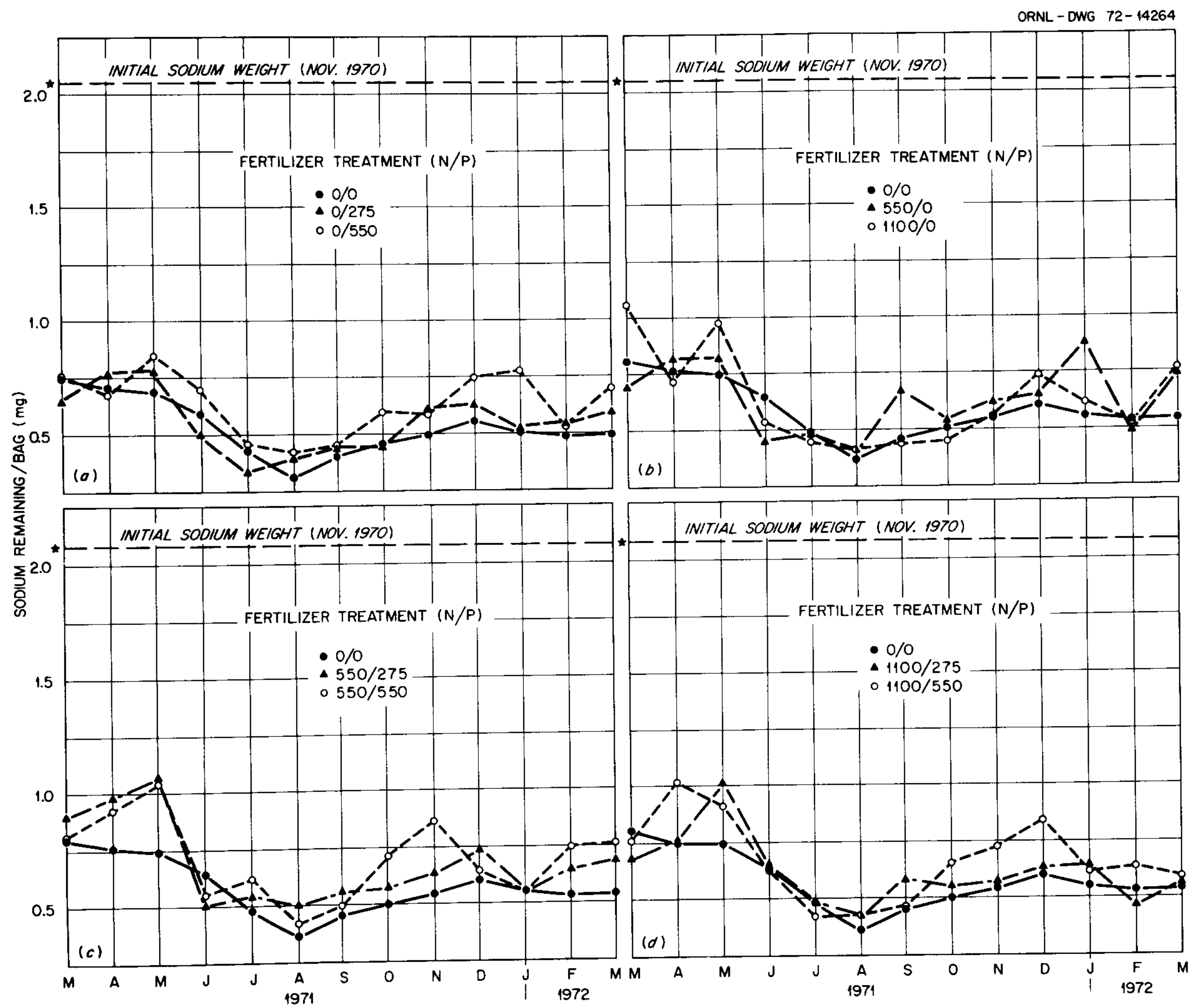

Figure 35. Temporal distribution of sodium remaining in white oak litter bags following application of fertilizer treatments. Standard deviations are presented in Table 21, Appendix D. Sodium content exhibited no consistent response to fertilization.

Soil Solution

Sodium movement in the soil solution. Sodium loss in the soil solution was not altered by nitrogen treatment nor was there any modification of the sodium concentration in soil leachate due to nitrogen treatment (Figure 36). Phosphorus treatment significantly increased sodium concentration and loss in the soil solution. Although there was less sodium released from the litter due to reduced microbial activity, there was also less immobilization of incoming sodium as a result of reduced microbial populations. Consequently, the added sodium was leached from the litter and appeared in the soil solution.

Sodium loss in this study ranged from 0.52 to 0.99 g/m^2, which agrees with the annual sodium loss in stream flow from Walker Branch Watershed (0.50 g/m^2) (Swank and Elwood 1971). Best (1971) found sodium loss from deciduous litter to be 0.87 g/m^2 per year. Likens *et al*. (1970) found annual sodium loss to range from 0.11 to 3.21 g/m^2, while Cochran *et al*. (1970) found sodium loss at 15 cm to range from 0.08 to 1.13 g/m^2. Due to the erratic nature of the sodium data, it is difficult to draw any sound conclusions. Even though the effect of fertilization on the sodium content of the litter and soil solution was statistically significant, in practical terms the effect of fertilization was probably of no significance.

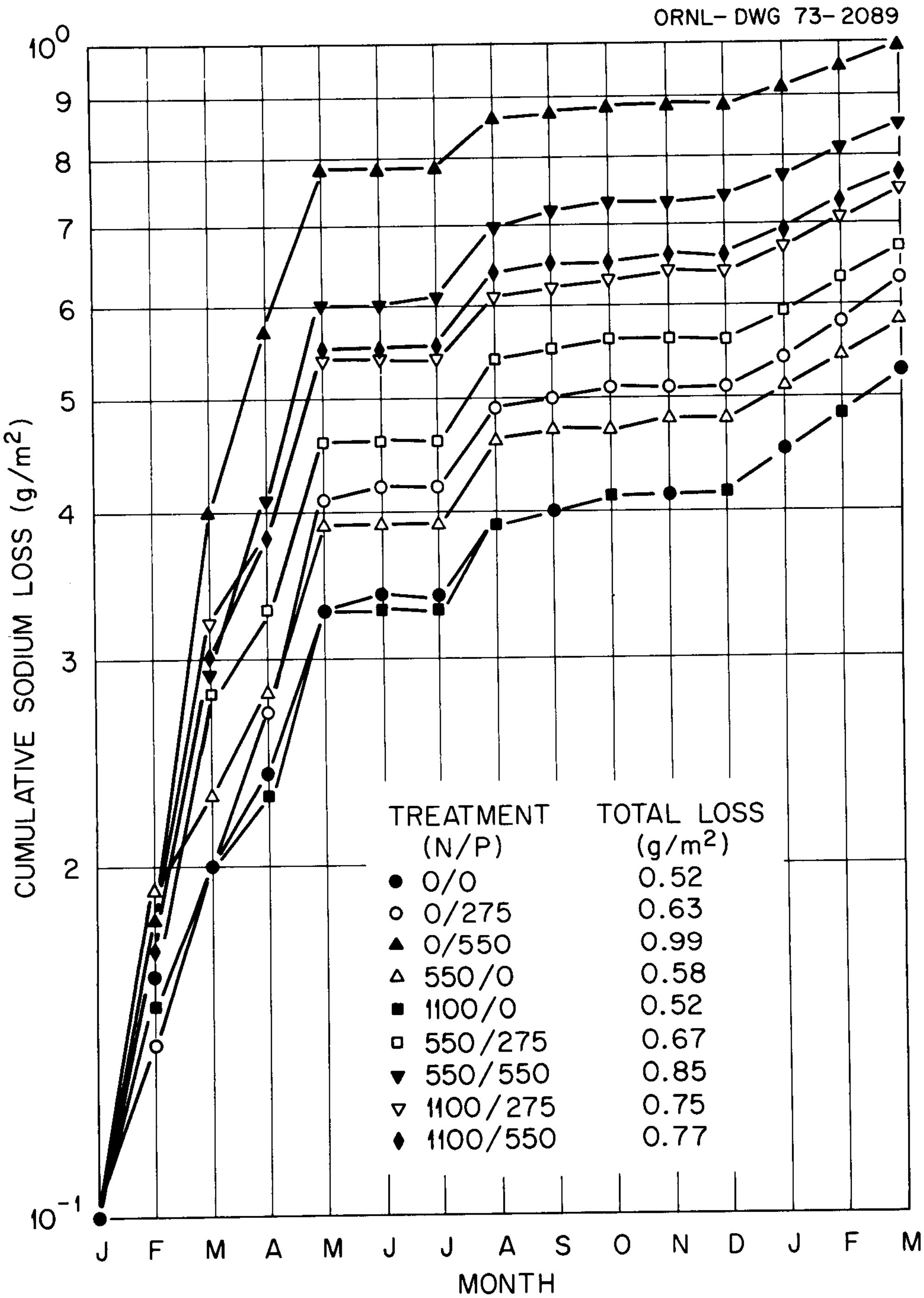

Figure 36. Cumulative sodium loss (g/m^2) from the litter and top 10 cm of the mineral soil in response to fertilizer treatment. Phosphorus treatment significantly increased sodium loss due to reduced microbial immobilization of sodium.

XI. ADDITION–LOSS BALANCES FOR NITROGEN, PHOSPHORUS, AND CALCIUM

Additions and losses of nitrogen, phosphorus, and calcium are summarized in Table 10. Additions represent only the amount of each element added through fertilization and do not include any natural input. Losses represent the amount of each element that moved past the 10-cm soil depth and do not necessarily represent losses from the soil profile or the rooting zone.

It was previously postulated that solubilization of organic matter was an important process contributing to total nitrogen loss. The nitrogen loss from the 1100/275 treatment (135.76 g/m^2) indicates that at least 25 g/m^2 of nitrogen was mobilized from litter and soil nitrogen pools. This estimate does not include volatilization or plant uptake and therefore should be regarded as a lower limit on losses due to solubilization. The lower loss from the 1100/550 treatment (88.34 g/m^2) supports the hypothesis that nitrogen loss was reduced by the formation of insoluble calcium ammonium phosphate compounds. Mees and Tomlinson (1964) and Hauck and Stephenson (1965) have noted that nitrogen volatilization loss was reduced when urea was applied in conjunction with mono-calcium phosphate. They attributed this reduction to a lower pH of hydrolysis. Thus when urea was applied in conjunction with concentrated superphosphate, volatilization loss was reduced, and leaching losses were reduced due to additional calcium being available for incorporation into insoluble calcium ammonium phosphate. These compounds must have been formed in the top 10 cm of the mineral soil,

Table 10. Partial summary of nitrogen, phosphorus, and calcium additions and losses following nitrogen and phosphorus fertilization. The values presented are in g/m^2.

Compartment	Fertilizer Treatment Level (Nitrogen/Phosphorus)								
	0/0	0/275	0/550	550/0	1100/0	550/275	550/550	1100/275	1100/550
<u>Nitrogen</u>									
Fertilizer Addition	0.00	0.00	0.00	55.00	110.00	55.00	55.00	110.00	110.00
0_1 Litter	18.02	17.30	14.61	18.05	15.92	16.90	18.98	14.99	16.59
0_2 Litter	9.94	7.95	8.14	7.90	9.71	8.70	9.39	9.92	9.86
Mineral Soil	173.88								
Soil Solution Loss	1.20	1.35	1.33	45.86	84.44	63.70	56.84	135.76	88.34
Addition - Loss				9.14	25.56	-8.70	-1.84	-25.76	21.66
<u>Phosphorus</u>									
Fertilizer Addition	0.00	27.50	55.00	0.00	0.00	27.50	55.00	27.50	55.00
0_1 Litter	0.37	0.41	0.40	0.69	0.87	0.74	1.71	0.70	0.91
0_2 Litter	0.47	1.03	2.01	0.32	0.34	1.66	4.53	1.81	2.79
Mineral Soil	32.40								
Soil Solution Loss	0.22	2.08	27.07	0.05	0.11	8.69	15.82	10.16	10.66
Addition - Loss		25.42	27.93			18.81	39.18	17.34	44.34
<u>Calcium</u>									
Fertilizer Addition	0.00	54.56	109.12	0.00	0.00	54.56	109.12	54.56	109.12
0_1 Litter	14.21	13.92	15.50	15.62	14.08	13.61	17.98	12.67	14.21
0_2 Litter	15.82	13.17	14.92	11.51	14.13	13.27	17.72	14.55	15.82
Mineral Soil	86.40								
Soil Solution Loss	2.26	5.34	21.17	5.68	5.31	6.04	7.60	7.74	10.44
Addition - Loss		49.22	87.95			48.52	101.52	46.82	98.68

because there was no evidence of nitrogen accumulation in the unconfined litter. Although volatilization was not quantified, the loss from the 1100/0 treatment (84.44 g/m^2) suggests that at least 26 g/m^2 or 23% of the added nitrogen was lost by volatilization. This estimate is low because solubilization of organic matter undoubtedly contributed some of the nitrogen lost in the soil solution. Volatilization from the 550/0 treatment was about the same percent as from the 1100/0 treatment. The greater loss of nitrogen in the soil solution when phosphorus was added with nitrogen suggests that volatilization was reduced in the presence of phosphorus. This phenomenon has been shown to be due to a lower pH of hydrolysis (Mees and Tomlinson 1964).

Phosphorus losses are in general agreement with the nitrogen fixation hypothesis. Equivalent amounts of phosphorus were lost from the 1100/275 and 1100/550 treatments, indicating greater fixation (44.34 vs 17.34 g/m^2) at the higher phosphorus level. Chemical fixation appears to be the best explanation since increasing phosphorus level reduced microbial population level (25% lower population in the 1100/275 treatment than in the 1100/550 treatment). The formation of calcium ammonium phosphate is further substantiated by the fact that more phosphorus was lost from the 550/550 than the 1100/550 treatment due to less nitrogen being available for combination with phosphorus and calcium. Also, it may be that phosphorus loss was more a function of pH, in which case less urea addition would lower pH and increase phosphorus solubility. This latter hypothesis is supported by the 0/275 and 0/550 treatment responses; the 0/550 addition exceeded the pH buffering capacity of the soil which resulted in greater phosphorus loss.

Calcium losses provide further evidence for chemical fixation of nitrogen because 14% of the added calcium was lost from the 1100/275 and 9% from the 1100/550 or a tie up of 17.34 vs 44.34 g/m^2. In comparison to the nitrogen and phosphorus additions a much smaller percentage of the added calcium was lost from all treatments. This supports the hypothesis of biological immobilization of calcium.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study considered the effects of nitrogen and phosphorus additions on: (1) loss of weight from white oak, red maple, and black gum leaf litter; (2) dynamics of nitrogen, phosphorus, potassium, calcium, magnesium, and sodium in the litter; (3) the flux of the previously named elements in the soil solution; (4) litter and soil microfloral population; and (5) litter microfaunal populations.

Specific Conclusions

The results of this study are summarized in Table 11. These data and associated statistical analyses support the following conclusions.

(1) The 550-kg/ha phosphorus level reduced white oak, red maple, and black gum weight loss by 4, 1, and 3%, respectively, while weight reduction at the 275-kg/ha level was 3, 1, and 2%, respectively.

(2) Weight loss from white oak and red maple was increased by 2% at the 1100-kg/ha nitrogen level and by 1% at the 550-kg/ha nitrogen level. Black gum weight loss was not altered at the 550-kg/ha nitrogen level, but it was increased by 1% at the 1100-kg/ha level.

(3) The interaction of nitrogen and phosphorus generally reduced white oak and red maple weight loss by approximately 1 to 3%. Black gum weight loss did not respond to the interaction of nitrogen and phosphorus.

Table 11. Summary of analyses of variance pertaining to the effect of nitrogen (N), phosphorus (P), and the interaction of nitrogen and phosphorus (NP) fertilizer on weight loss and nutrient content of the confined and unconfined litter, the soil solution, and the microbiota.

Component	Weight Loss			Total Nitrogen Content			Ammonium Nitrogen Content			Phosphorus Content			Potassium Content			Calcium Content			Magnesium Content			Sodium Content			Population Level		
	N	P	NP	N	P	NP	N	P	NP	N	P	NP	N	P	NP	N	P	NP	N	P	NP	N	P	NP	N	P	NP
White Oak Leaves	+[a]	-	-	+	-	+				o	+	+	+	o	+	+	+	o	+	-	+	+	+	o			
Red Maple Leaves	+	o	-																								
Black Gum Leaves	+	-	o																								
Unconfined O_1	o	o	o	o	o	o				+	+	+	+	+	+	+	+	+	+	-	+	-	o	+			
Unconfined O_2	+	o	+	o	o	-				+	+	+	-	-	-	-	-	-	o	-	-	-	-	-			
Soil Solution				+	o	o	+	o	o	o	+	+	o	o	o	o	o	o	o	+	o	o	+	+			
Litter Bacteria																									+	-	o
Soil Bacteria																									+	o	o
Litter Fungi																									o	o	o
Soil Fungi																									o	+	+
Oak Microfauna																									-	o	o
Red Maple Microfauna																									-	+	o
Black Gum Microfauna																									o	o	o

[a] A (+) indicates significant increase (P = 0.05), a (-) indicates a significant decrease, and a (o) indicates the component in question did not respond to the treatment.

(4) Fertilization had no effect on the standing crop of unconfined O_1 litter 1 year after fertilization. The O_2 litter weight was reduced an average of 104 g/m^2 by the 550-kg/ha nitrogen level and 40 g/m^2 by the 1100-kg/ha level. Phosphorus reduced O_2 litter weight by 160 to 280 g/m^2.

(5) Nitrogen treatment at the 550-kg/ha level significantly increased mean calcium, sodium, magnesium, potassium, and nitrogen contents of white oak litter bags by approximately 7.0, 0.1, 0.6, 0.4, and 10.0 mg/bag respectively. Nitrogen treatment at the 1100-kg/ha level increased mean contents of the same elements by approximately 7.0, <0.1, 0.7, 0.3, and 13.0 mg/bag.

(6) Phosphorus addition at both the 275- and 550-kg/ha levels significantly reduced mean magnesium content of white oak litter by 0.4 mg/bag, while nitrogen content was reduced by 4.0 mg/bag. Calcium, sodium, and phosphorus contents were increased by 5.0, <0.1, and 2.0 mg/bag respectively at the 275-kg/ha level and 7.0, 0.1, and 4.0 mg/bag at the 550-kg/ha level.

(7) The interaction of nitrogen and phosphorus, with the exception of the 0/550 combination (-0.4 mg/bag), increased mean magnesium content of white oak litter by 0.1 to 1.0 mg/bag. The 0/275 and 0/550 combinations lost 0.4 mg/bag of potassium, while all other combination means increased by approximately 0.1 mg/bag. Mean phosphorus content increased by 1.0 to 3.0 mg/bag in all combinations except the 550/0 and 1100/0, where losses of approximately 1.0 mg/bag were recorded.

(8) Nitrogen addition at the 550-kg/ha level increased the mean loss of ammonium in the soil solution by 12.0 g/m^2 and the mean loss

of total nitrogen by 42.0 g/m^2. The 1100-kg/ha level of nitrogen addition increased mean ammonium and total nitrogen loss in the soil solution by 20.0 and 81.0 g/m^2 respectively. All other element losses were not altered by nitrogen addition.

(9) Phosphorus addition at the 275-kg/ha level increased mean calcium, sodium, magnesium, and phosphorus loss in the soil solution by 2.0, 0.1, 0.4, and 7.0 g/m^2 respectively. Calcium, sodium, magnesium, and phosphorus losses at the 550-kg/ha level were increased by 9.0, 0.3, 2.0, and 18.0 g/m^2 respectively. Ammonium and total nitrogen losses were not altered by phosphorus additions.

(10) The interaction of nitrogen and phosphorus significantly increased the mean loss of calcium (3.0 to 19.0 g/m^2), sodium ($<$0.1 to 0.4 g/m^2), ammonium (0.1 to 22.0 g/m^2), total nitrogen (0.2 to 134.0 g/m^2), and phosphorus (2.0 to 21.0 g/m^2) in the soil solution. The interaction of nitrogen and phosphorus reduced phosphorus loss from the 550/0 and 1100/0 treatments by 75 and 50% respectively.

(11) Solubilization of organic matter, chemical fixation, and volatilization were important in regulating the total nitrogen loss in the soil solution.

(12) Nitrogen addition stimulated bacterial population growth, while phosphorus addition retarded bacterial population growth.

(13) The litter fungi did not respond to fertilization, while phosphorus increased soil fungal populations.

(14) Nitrogen treatment significantly reduced the total population of invertebrates in white oak litter. Invertebrate populations in red maple litter increased after phosphorus addition and decreased after

nitrogen addition. Invertebrates inhabiting black gum litter did not respond to fertilization.

General Conclusions

The primary objective of this study was to evaluate the effect of nitrogen and phosphorus additions on the decomposition and mineralization of fresh deciduous litter. A large portion of the nutrient capital in a forest ecosystem is contained in the litter. Consequently, any perturbation which alters the nutrient status of the litter is of concern to both forester and environmentalist.

The observed effect of nitrogen and phosphorus fertilization on the decomposition of deciduous litter was primarily due to the effect of added nitrogen and phosphorus on the microflora. The microfauna, while appearing to be of little importance in this study, is certainly an important component of the decomposition and mineralization process because of its role as a preconditioner of the litter. Any fertilizer addition that alters microbial populations will produce both short-term and long-term changes in normal nutrient pools. Although the results of this study indicate that the effects of added nitrogen and phosphorus were both minimal and of relatively short duration (generally less than 1 year), when these responses are scaled-up to watershed or drainage basin proportions then even the smallest alteration takes on added significance.

It appears that a single application, or two applications of fertilizer separated by several years, would not have a detrimental impact on the quality or quantity of deciduous litter. However, the fertilization of a forest must be approached in much the same manner as the fertilization of a field crop. After a number of site, economic, and social factors are weighed, a decision must be made on the nutrients to be applied, their form and level of application, and the method and timing of the application so as to achieve optimum growth with minimum environmental perturbation. Application of urban and industrial by-products and waste water requires an evaluation of the added variables of moisture and organic material plus the possibility of introducing toxic metals and chemical compounds into the forest ecosystem. Nutrient enrichment with waste material, especially if applied in a liquid form would have a much greater effect on decomposer organisms than a single application of commercial fertilizer (Sopper 1971). Consequently, research needs to be conducted to assess the effects of several forms of nutrient enrichment.

Future studies of forest fertilization should be directed at the O_1 and O_2 litter layers and the mineral soil. The more humified O_2 segment merits special attention, for it is there that nutrient additions (especially nitrogen) have their greatest effect. The relation between microbial activity and the production of the bicarbonate ion needs to be investigated, especially in relation to the leaching loss of certain elements. Studies similar to this one need to be conducted in coniferous monocultures typical of those found in the Southeastern United States, for it is there that fertilization will most likely become a standard practice.

A single application of nitrogen and/or phosphorus fertilizer to a deciduous watershed, if made at present commercial rates, would have a minimal long-term effect on the quality of water discharged from the watershed or the general nutrient status of the litter and soil. On a short-term basis, increased concentrations of added elements and carbon can be expected in stream water. The short-term effect of fertilization on the nutrient content of the soil solution should last no longer than 6 to 8 months after fertilization, with some residual effects being detectable for a year or more. Due to the apparent antagonistic effects of nitrogen and phosphorus, it might be possible through careful pairing of nitrogen and phosphorus levels to increase available nitrogen while keeping losses of other elements to a minimum.

This study provides information, heretofore unavailable, on the effects of fertilization on certain segments of the deciduous forest and adds to the knowledge relating to other segments of the forest ecosystem which have been previously quantified. It is only through a thorough understanding of the operation of the component parts that one is able to predict the response of the whole system to any perturbation.

LITERATURE CITED

Allison, F. E. 1964. The soil nitrogen balance sheet, a continuing enigma. In Soil and fertilizer nitrogen research. Tenn. Valley Auth., Wilson Dam, Ala. p. 1-17.

Allison, F. E. and C. J. Klein. 1961. Comparative rates of decomposition in soil of wood and bark particles of several soft wood species. Soil. Sci. Soc. Amer. Proc. 25: 193-196.

Allison, F. E. and R. M. Murphy. 1962. Comparative rates of decomposition in soil of wood and bark particles of several hardwood species. Soil. Sci. Soc. Amer. Proc. 26: 463-466.

Allison, F. E. and R. M. Murphy. 1963. Comparative rates of decomposition in soil of wood and bark particles of several species of pines. Soil Sci. Soc. Amer. Proc. 27: 309-312.

Allison, F. E., R. M. Murphy and C. J. Klein. 1963. Nitrogen requirements for the decomposition of various kinds of finely ground woods in soil. Soil Sci. 96: 187-190.

Altman, P. L. and D. S. Dittmer. 1966. Environmental biology. Federation of American Societies for Experimental Biology. Bethesda, Md. 694 p.

Auerbach, S. I. 1972. Ecological Sciences Division annual progress report 1971. ORNL-4759. p. 41-45.

Bear, F. E. 1964. Chemistry of the soil. Reinhold Publishing Co., New York. 515 p.

Bengston, G. W. 1970a. Placement influences the effectiveness of phosphates for pine seedlings. In C. T. Youngberg and C. B. Davey (eds.) Tree growth and forest soils. Oreg. State Univ. Press, Corvallis, Oreg. 527 p.

Bengston, G. W. 1970b. Forest soil improvement through chemical amendments. J. Forest. 68: 343-347.

Berger, K. C. and P. F. Pratt. 1963. Advances in secondary and micronutrient fertilization. In M. H. McVicker, G. L. Bridger, and L. B. Nelson (eds.) Fertilizer Technology and Usage. Soil Sci. Soc. Amer. Madison, Wisc. 314 p.

Best, G. R. 1971. Potassium, sodium, calcium, and magnesium flux in a mature hardwood forest watershed and an eastern white pine forest watershed at Coweeta. Masters thesis. Univ. of Ga. 87 p.

Bhure, N. D. 1970. Nitrogen losses by volatization from urea applied to forest soil. Can. Forest. Serv. Bi-monthly Res. Notes 26(3): 30-31.

Black, C. A. 1957. Soil-plant relationships. John Wiley & Sons, Inc. New York. 332 p.

Black, C. A. 1965. Methods of soil analysis. Amer. Soc. of Agron. Madison, Wisc. 1572 p.

Bocock, K. L. 1963. Changes in the amount of nitrogen in decomposing leaf litter of sessile oak. (Quercus petraea). J. Ecol. 51: 555-566.

Bocock, K. L. 1964. Changes in the amounts of dry matter, nitrogen, carbon, and energy in decomposing woodland leaf litter in relation to the activities of soil fauna. J. Ecol. 52: 273-284.

Bocock, K. L. and O. J. W. Gilbert. 1957. The disappearance of leaf litter under different woodland conditions. Plant Soil 9(2): 179-186.

Braun, E. L. 1950. Deciduous forest of Eastern North America. Blankiston Co., Philadelphia. 596 p.

Buckman, H. O. and N. C. Brady. 1969. The nature and properties of soils. The Macmillan Co., New York. 653 p.

Caldwell, B. B. and W. A. DeLong. 1950. Studies of the composition of deciduous forest tree leaves before and after partial decomposition. Sci. Agr. 30: 456-466.

Carlisle, A., A. H. F. Brown and E. J. White. 1966. The organic matter and nutrient elements in the precipitation beneath a sessile oak (Quercus petraea) canopy. J. Ecol. 54: 87-98.

Carlisle, A., A. H. F. Brown and E. J. White. 1967. The nutrient content of tree stem flow and ground flora litter and leachates in sessile oak (Quercus petraea) woodland. J. Ecol. 55: 615-627.

Cochran, P. H., G. M. Marion, and A. L. Leaf. 1970. Variations in tension lysimeter leachate volumes. Soil Sci. Soc. Amer. Proc. 34: 309-311.

Cole, D. W. 1958. Alundum tension lysimeters. Soil Sci. 85: 293-296.

Cole, D. W. and S. P. Gessel. 1968. Cedar River research--a program for studying the pathways, rates, and processes of elemental cycling in a forest ecosystem. Inst. For. Prod. Univ. of Wash., Coll. of For. Res. 53 p.

Cole, D. W., S. P. Gessel and E. E. Held. 1961. Tension lysimeter studies of ion and moisture movement in glacial till and a coral atoll soil. Soil Sci. Soc. Amer. Proc. 25: 321-325.

Crossley, D. A. and M. P. Hoglund. 1962. A litter-bag method for the study of microarthropods inhabiting leaf litter. Ecology 43: 571-574.

Crossley, D. A. and M. Witkamp. 1963. Effects of pesticide on biota and breakdown of forest litter. Int. Cong. Soil Sci. Trans. 3: 887-892.

Crossley, D. A. and M. Witkamp. 1964. Forest soil mites and mineral cycling. Acarologia 6: 138-145.

Curlin, J. W. 1963. Response of natural stands of shortleaf pine to thinning and fertilization with nitrogen and phosphorus. Soil Sci. Soc. Amer. Proc. 27: 234-236.

Curlin, J. W. and D. J. Nelson. 1968. Walker Branch Watershed Project: objective, facilities, and ecological characteristics. ORNL-TM-2271. 106 p.

Drift, J. van der. and M. Witkamp. 1959. The significance of the breakdown of oak litter by Enoicyla pusilla Brum. Archs. Neerl. Zool. 13: 486-492.

DuPlessis, M. C. F. and W. Kroontje. 1964. The relationship between pH and ammonia from prilled urea applied to slash pine. Soil Sci. Soc. Amer. Proc. 34: 513-516.

Edwards, C. A., D. E. Reichle, and D. A. Crossley. 1969. Experimental manipulation of soil invertebrate populations for trophic studies. Ecology 50: 495-517.

Edwards, C. A., D. E. Reichle, and D. A. Crossley. 1970. The role of soil invertebrates in turnover of organic matter and nutrients. In Analysis of temperate forest ecosystems. D. E. Reichle (ed.) Springer-Verlag, New York. 304 p.

Ernst, J. W. and H. F. Massey. 1960. The effect of several factors on volatilization of ammonia formed from urea in the soil. Soil Sci. Soc. Amer. Proc. 24: 87-90.

Fiedler, F. J. and G. F. Weetman. 1971. Losses of nitrogen from surface applied urea and other effects of season of fertilizer application on growth response. In International union of forest research organizations meeting. Gainesville, Fla. 25 p.

Foster, J. W. 1949. Chemical activities of fungi. Academic Press, New York. 648 p.

Gasdorf, J. K. R. 1964. Some factors affecting losses of ammonia from urea and ammonium sulfate applied to soils. Soil Sci. 15: 258-272.

Goldstein, R. A. and J. B. Mankin. 1972. PROSPER: A model of atmosphere-soil-plant water flow. Proceedings of the 1972 Summer Computer Simulation Conference, June 14, 15, 16. San Diego, California. pp. 1176-1181.

Hauck, R. D. and H. F. Stephenson. 1965. Nitrification of nitrogen fertilizers. Effect of nitrogen source, size and pH of the granule, and concentration. J. Agr. Food Chem. 13: 486-492.

Henderson, G. S. 1972a. Litter biomass and nutrient contents in four forest stands on Walker Branch Watershed. Eastern Deciduous Forest Biome Memo Report 71-91. 10 p.

Henderson, G. S. 1972b. Analytical procedures used in the eastern deciduous forest biome. Eastern Deciduous Forest Biome Memo Report (In press).

Holland, J. Z. 1953. A meteorological survey of the Oak Ridge area. U.S. AEC Report ORO-99. 584 p.

Huhta, V., M. Nurminen and A. Valpas. 1969. Further notes on the effect of silvicultural practices upon the fauna of coniferous forest soil. Ann. Zool. Fennici 6: 327-334.

Hume, A. and A. A. Brooks. 1970. The SADS program, statistical analysis of data subsets. Computing Technology Center Report 19, Oak Ridge National Laboratory, Oak Ridge, Tenn. 345 p.

Isensee, A. R. and L. M. Walsh. 1971. Influence of banded fertilizers on the chemical environment surrounding the band. J. Sci. Food Agr. 22(3): 105-110.

Kahn, H. L. 1971. Analytical methods for atomic absorption spectrophotometry. Perkin-Elmer Co., Norwalk, Conn. 135 p.

Kucera, C. L. 1959. Weathering characteristics of deciduous leaf litter. Ecology 40: 485-487.

Kurcheva, G. F. 1960. Role of invertebrates in the decomposition of oak litter. Sov. Soil Sci. 4: 360-365.

Likens, G. E., F. H. Bormann, N. M. Johnson, and R. S. Pierce. 1967. The calcium, magnesium, potassium, and sodium budgets of a small forested ecosystem. Ecology 48: 772-785.

Likens, G. E., F. H. Bormann, N. M. Johnson, D. W. Fisher, and R. S. Pierce. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook Watershed Ecosystem. Ecol. Monogr. 40: 23-47.

Lundgren, D. P. 1960. Phosphate analysis with the technicon auto-analyzer. Anal. Chem. 32: 824-828.

Lunt, H. A. 1935. Effect of weathering upon dry matter and composition of hardwood leaves. Jour. Forestry 33: 607-609.

Lutz, H. J. and R. E. Chandler. 1946. Forest soils. John Wiley and Sons, New York. 514 p.

Martin, J. P. and K. Haider. 1971. Microbial activity in relation to soil humus formation. Soil Sci. 3: 54-64.

McBrayer, J. F. and D. E. Reichle. 1971. Trophic structure and feeding rates of forest soil invertebrate populations. Oikos 22: 381-388.

McMaster, W. M. and H. D. Waller. 1965. Geology and soils of white-oak creek basin, Tennessee. ORNL-TM-1108. 37 p.

Mecklenburg, R. A. and H. B. Tukey, Jr. 1964. Influence of foliar leaching on root uptake and translocation of calcium-45 to the stems and foliage of *Phaseolus vulgaris*. Plant Physiol. 39: 533-536.

McFee, W. W. and E. L. Stone. 1966. The persistence of decaying wood in the humus layers of northern forests. Soil Sci. Soc. Amer. Proc. 30: 513-516.

Mees, G. C. and T. E. Tomlinson. 1964. Urea as a fertilizer. Jour. Agric. Sci. 62: 199-205.

Metz, L. J. 1952. Weight and nitrogen and calcium content of the annual litter fall of forests in the South Carolina piedmont. Soil Sci. Soc. Amer. Proc. 16: 38-41.

Meyer, R. D., R. A. Olson, and H. F. Rhoades. 1961. Ammonia losses from fertilized Nebraska soils. Agron. J. 51: 746-749.

Monk, C. D. 1971. Leaf decomposition and loss of ^{45}Ca from deciduous and evergreen trees. Amer. Midland Natur. 86: 379-385.

Mustanoja, K. J. and A. L. Leaf. 1965. Forest fertilization research 1957-1964. The Botanical Rev. 31(2): 151-246.

Nason, A. and W. D. McElroy. 1963. Modes of action of the essential elements. *In* F. C. Steward (ed.) Plant physiology a treatise, Vol. III. Academic Press, New York. pp. 451-536.

Nykvist, N. 1962. Leaching and decomposition of litter, experiments on leaf of *Alnus glutinosa*, *Fagus silvatica*, and *Quercus robur*. Oikos 13: 232-248.

Ogner, G. 1972. The composition of a forest raw humus after fertilization with urea. Soil Sci. 133: 440-447.

Ogner, G. and M. Schnitzer. 1970. Humic substances: Fluvic acid-dialkyl phthalate complexes and their role in pollution. Science 170: 317-318.

Olsen, C. 1933. Studies of nitrogen fixation. 1. Nitrogen fixation in dead leaves of forest beds. Compt. Rend. des Trav. der Lab. Carlsberg 19(9): 1-36.

Overrein, L. N. 1969. Lysimeter studies on tracer nitrogen in forest soil. Soil Sci. 107: 149-159.

Overrein, L. N. and P. G. Moe. 1967. Factors affecting urea hydrolysis and ammonia volatization in soil. Soil Sci. Soc. Amer. Proc. 31: 57-61.

Ovington, J. D. 1960. Quantitative ecology and the woodland ecosystem concept. In J. B. Cragg (ed.) Advance. Ecol. Res. 1: 103-193.

Parle, J. N. 1963. Microorganisms in the intestines of earthworms. J. Gen. Microbiol. 31: 1-10.

Pauli, F. W. 1970. Humification of straw at different nitrogen levels followed by acriflarine absorption and light absorption. Plant Soil 33: 313-324.

Patrick, Z. A. 1971. Phytotoxic substances associated with the decomposition in soil of plant residues. Soil Sci. 3: 13-19.

Pearse, A. S. 1946. Observations on the microfauna of the Duke forest. Ecol. Mono. 16: 127-150.

Peters, L. N., D. F. Grigal, J. W. Curlin, and W. J. Selvidge. 1970. Walker Branch Watershed project: chemical, physical and morphological properties of the soils of Walker Branch Watershed. ORNL-TM-2968. 96 p.

Remeznov, N. P. 1958. Relation between biological accumulation and eluvial process under forest cover. Sov. Soil Sci. 6: 589-598.

Remeznov, N. P. 1959. Method of studying the biological cycle of elements in forest. Sov. Soil Sci. 7: 59-67.

Remeznov, N. P. 1961. Decomposition of forest litter and the cycle of elements in an oak forest. Sov. Soil Sci. 9: 703-711.

Riekerk, H. 1971. The mobility of phosphorus, potassium, and calcium in a forest soil. Soil Sci. Soc. Amer. Proc. 35: 350-356.

Roberge, M. R. 1972. Some factors affecting the soluble ammonium-nitrogen content of black spruce humus. Soil Sci. Soc. Amer. Proc. 36: 350-353.

Rodin, L. E. and N. I. Bazilevich. 1967. Production and mineral cycling in terrestrial vegetation. Scripta Technica Ltd., London. 288 p.

Scott, D. R. M. 1955. Amount and chemical composition of the organic matter contributed by overstory and understory vegetation to forest soil. Yale Univ. School of Forest. Bull. No. 62. 73 p.

Shanks, R. E. and J. S. Olson. 1961. First-year breakdown of leaf litter in southern Appalachian forests. Science 134: 194-195.

Sheppard, J. D., G. S. Henderson, T. Grizzard and M. Heath. 1973. Hydrology of a forested catchment: I. Water balance from 1967-1972 on Walker Branch Watershed. (Submitted to Water Resources Research).

Sopper, W. E. 1971. Disposal of municipal waste water through forest irrigation. Environ. Pollut. 1: 263-284.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, New York. 481 p.

Stenlid, G. 1958. Salt losses and redistribution of salts in higher plants. Encyclopedia of Plant Physiol. 4: 615-637.

Swank, W. T. and J. L. Elwood. 1971. The seasonal and annual flux of cations for forested ecosystems in the Appalachian highlands. Eastern Deciduous Forest Biome Memo Report 71-134. 21 p.

Takahashi, D. T. 1970. Fate of unrecovered fertilizer nitrogen in lysimeter studies with N^{15}. Hawaiian Planter's Record 58(7): 95-101.

Tamm, C. O. 1969. Site damages by thinning due to removal of organic matter and plant nutrients. Department of Plant Ecology and Forest Soils. Publication No. 78. Royal College of Forestry, Stockholm, Sweden. 6 p.

Thomas, W. A. 1969. Accumulation and cycling of calcium by dogwood trees. Ecol. Monogr. 34: 101-120.

Thomas, W. A. 1970. Weight and calcium losses from decomposing tree leaves on land and in water. J. Appl. Ecol. 7: 237-241.

Tisdale, S. L. and W. L. Nelson. 1966. Soil fertility and fertilizers. The Macmillan Co., New York. 694 p.

Todd, R. C. and K. Cromack, Jr. 1972. Concentration of phosphorus, potassium, calcium and magnesium by mixed deciduous litter inhabiting fungi and bacteria. Eastern Deciduous Forest Biome Memo Report 72-8. 10 p.

Tribe, H. T. 1960a. Aspects of decomposition of cellulose in Canadian soils. Can. J. Microbiol. 6: 309-316.

Tribe, H. T. 1960b. Aspects of decomposition of cellulose in Canadian soils. Can. J. Microbiol. 6: 317-323.

Tukey, H. B., Jr. 1970. The leaching of substances from plants. Ann. Rev. of Plant Physiol. 21: 305-324.

Tullgren, A. 1918. Ein sehr Einfacher Ausleseapparat fur Terricol Tierformen. Z. Angew. Ent. 4: 149-150.

Volk, G. M. 1959. Volatile loss of ammonia following surface application of urea to turf or bare soil. Agron. J. 51: 746-749.

Volk, G. M. 1970. Gaseous loss of ammonia from prilled urea applied to slash pine. Soil Sci. Soc. Amer. Proc. 34: 513-516.

Wahhab, A., A. M. Khan, and M. Ishaq. 1960. Nitrification of urea and its loss through volatization under different soil conditions. J. Agr. Sci. 55: 47-51.

Waksman, S. A. 1927. Principles of soil microbiology. Williams and Wilkins, Baltimore, Md. 897 p.

Waksman, S. A. and F. G. Tenney. 1928. Composition of natural organic materials and their decomposition in the soil. Soil Sci. 26: 155-171.

Weber, D. F. and P. L. Gainey. 1962. Relative sensitivity of nitrifying organisms to hydrogen ions in soils and in solutions. Soil Sci. 94: 138-145.

White, D. P. and A. L. Leaf. 1956. Forest fertilization. Tech. Publ. 81. State Univ. Coll. of Forest. at Syracuse. 305 p.

Witkamp, M. 1960. Seasonal fluctuations of the fungus flora in mull and mor of an oak forest. Meded. Inst. Toegep. Biol. Onderz. Nature 46: 370-376.

Witkamp, M. 1963. Microbial populations of leaf litter in relation to environmental conditions and decomposition. Ecology 44: 370-377.

Witkamp, M. 1964. Environmental influences on microbial populations and activity of the forest floor. Int. Congr. Soil Sci. Trans. 3: 647-654.

Witkamp, M. 1966. Decomposition of leaf litter in relation to environment, microflora and microbial respiration. Ecology 47: 194-201.

Witkamp, M. 1969a. Environmental effects on microbial turnover of some mineral elements, part I - abiotic factors. Soil Biol. Biochem. 1: 167-176.

Witkamp, M. 1969b. Environmental effects on microbial turnover of some mineral elements, part II - biotic factors. Soil Biol. Biochem. 1: 177-184.

Witkamp, M. 1971a. Forest soil microflora and mineral cycling. In Productivity of forest proc., Brussels Symp. 1969. pp. 413-424.

Witkamp, M. 1971b. Soils as components of ecosystems. In R. F. Johnston, P. W. Frank, and S. D. Michener (eds.). Annual review of ecology and systematics, Vol. II. Annual Reviews, Inc., Palo Alto, California. 510 p.

Witkamp, M. and D. A. Crossley. 1966. The role of arthropods and microflora in breakdown of white oak litter. Pedobiologia 6: 293-303.

APPENDICES

APPENDIX A

Key to Appendix A

Columns 1 through 9 correspond to the following fertilizer treatments: (nitrogen/phosphorus) 0/0, 0/275, 0/550, 550/550, 550/0, 1100/550, 1100/0, 550/275, and 1100/275.

Rows 1 through 13 correspond to the following sampling dates for the white oak litter bags: March through December 1971 (1-10) and January through March 1972 (11-13).

Rows 1 through 3 correspond to the following sampling dates for both red maple and black gum litter bags: March and September 1971 and March 1972.

N = The number of observations making up the mean.

STD = The standard deviation of the mean.

Table 12. Weight in grams of the leaf material remaining (average array 1) and the weight of leaf material lost (average array 2) from white oak litter bags as a function of fertilizer treatment and time.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
1	N	12	12	12	12	12	12	12	12	12	108
	MEAN*[a]	5907	6232	6213	6348	6348	6284	6111	6379	6123	6216
	STD*	231	453	456	447	496	472	402	373	317	422
2	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	5498	5413	5523	5442	5409	5604	5165	5460	5315	5425
	STD*	326	894	293	383	261	308	441	388	284	438
3	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	5783	6005	6090	6193	5849	6025	5707	6053	5994	5967
	STD*	340	550	701	574	590	585	516	503	654	564
4	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	5511	5768	5641	5658	5291	5577	5345	5683	5463	5549
	STD*	514	701	640	693	529	603	606	587	795	630
5	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	4508	4658	5348	4618	4422	4982	4534	4870	4490	4714
	STD*	470	806	657	486	482	414	613	600	569	624
6	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3964	4583	4493	4365	4073	4108	3770	4349	3900	4180
	STD*	554	579	539	1030	560	704	719	779	607	715
7	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3581	3816	4010	3881	3462	3902	3388	3862	3695	3733
	STD*	337	260	303	349	405	360	356	465	387	403
8	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	4069	4307	4454	4532	4131	4334	3832	4353	4047	4229
	STD*	389	568	531	428	401	231	362	422	475	467
9	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3567	4373	4195	3855	3676	3803	3443	4232	3930	3897
	STD*	394	360	478	286	594	561	422	336	467	524
10	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3293	3602	4063	3512	3441	3803	3241	3876	3529	3596
	STD*	608	333	419	552	531	439	194	408	617	524
11	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3392	3996	4040	3573	3738	3958	3443	3974	3467	3731
	STD*	274	273	397	526	306	287	324	352	342	421
12	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3176	3729	3924	3500	3183	3575	3215	3610	3052	3441
	STD*	256	428	447	722	454	1151	438	186	691	639
13	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	2973	3659	3741	3172	3394	3512	3453	3573	3078	3395
	STD*	723	645	575	1025	479	430	304	923	630	695
SUMS	N	156	156	156	156	156	156	156	156	156	1404
	MEAN*	4249	4626	4749	4511	4340	4574	4203	4636	4314	4467
	STD*	1116	1047	983	1197	1107	1090	1091	1050	1156	1107

Table 12. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 2											
1	N	12	12	12	12	12	12	12	12	12	108
	MEAN[a]	1092	768	787	652	652	716	889	621	877	784
	STD*	231	453	456	447	496	472	402	373	317	422
2	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	1502	1587	1477	1558	1591	1396	1835	1540	1685	1575
	STD*	326	894	293	383	261	306	441	388	284	438
3	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	1217	995	910	807	1151	975	1292	947	1006	1033
	STD*	340	550	701	574	590	585	516	503	654	564
4	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	1489	1232	1359	1342	1709	1423	1655	1317	1537	1451
	STD*	514	701	640	693	529	603	606	587	795	630
5	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	2492	2342	1652	2382	2578	2018	2466	2130	2510	2286
	STD*	470	806	657	486	482	414	613	600	569	624
6	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3016	2417	2507	2635	2927	2892	3230	2651	3100	2820
	STD*	554	579	539	1030	560	704	719	779	607	715
7	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3419	3164	2990	3119	3538	3098	3612	3138	3305	3267
	STD*	337	260	303	349	405	360	356	465	387	403
8	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	2931	2693	2546	2468	2869	2666	3168	2647	2952	2771
	STD*	389	568	531	428	401	231	362	422	475	467
9	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3433	2627	2805	3145	3324	3197	3557	2768	3070	3103
	STD*	394	360	478	286	594	581	422	336	467	524
10	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3707	3398	2937	3488	3559	3197	3759	3124	3471	3404
	STD*	608	333	419	552	531	439	194	408	617	524
11	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3608	3004	2960	3427	3262	3042	3557	3026	3532	3269
	STD*	274	273	397	526	306	287	324	352	342	421
12	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3824	3271	3076	3500	3817	3425	3785	3390	3947	3559
	STD*	256	428	447	722	454	1151	438	186	691	639
13	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	4027	3341	3259	3828	3606	3488	3547	3427	3922	3605
	STD*	723	645	575	1025	479	430	304	923	630	695
SUMS	N	156	156	156	156	156	156	156	156	156	1404
	MEAN*	2751	2374	2251	2489	2660	2426	2797	2364	2686	2533
	STD*	1116	1047	983	1197	1107	1090	1091	1050	1156	1107

[a] MULTIPLY MEANS AND STANIARD DEVIATIONS BY 10 TC THE -3.

Table 13. Weight in grams of the leaf material remaining (average array 1) and the weight of leaf material lost (average array 2) from red maple litter bags as a function of fertilizer treatment and time.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
1	N	12	12	12	12	12	12	12	12	12	108
	MEAN* [a]	5622	5713	5512	5613	5406	5435	5565	5547	5458	5541
	STD*	431	266	335	330	601	212	263	467	268	370
2	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3101	3706	3493	3598	2967	2740	3029	3180	3130	3216
	STD*	480	1185	367	448	402	882	601	568	519	699
3	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	2797	3251	3433	3813	2957	3096	2892	3045	3033	3146
	STD*	729	257	740	1070	240	381	303	299	590	631
SUMS	N	36	36	36	36	36	36	36	36	36	324
	MEAN*	3840	4223	4146	4341	3777	3757	3829	3924	3873	3968
	STD*	1395	1289	1100	1139	1244	1332	1311	1247	1228	1257
AVERAGE ARRAY 2											
1	N	12	12	12	12	12	12	12	12	12	108
	MEAN* [a]	1378	1287	1488	1387	1594	1565	1435	1453	1542	1459
	STD*	431	266	335	330	601	212	263	467	268	370
2	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3899	3294	3507	3402	4032	4260	3971	3820	3870	3784
	STD*	480	1185	367	448	402	882	601	568	519	699
3	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	4203	3749	3567	3187	4043	3904	4108	3955	3967	3854
	STD*	729	257	740	1070	240	381	303	299	590	631
SUMS	N	36	36	36	36	36	36	36	36	36	324
	MEAN*	3160	2777	2854	2659	3223	3243	3171	3076	3127	3032
	STD*	1395	1289	1100	1139	1244	1332	1311	1247	1228	1257

[a] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE -3.

Table 14. Weight in grams of the leaf material remaining (average array 1) and the weight of leaf material lost (average array 2) from black gum litter bags as a function of fertilizer treatment and time.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
1	N	12	12	12	12	12	12	12	12	12	108
	MEAN*[a]	6453	6381	6300	6367	6500	6301	6378	6275	6227	6354
	STD*	201	373	225	186	166	287	193	259	348	262
2	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	2675	2724	3092	2973	2689	2677	2170	2917	2874	2755
	STD*	262	396	445	559	483	613	327	1131	455	604
3	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	1972	2769	2842	2505	1938	2452	2004	2312	2340	2348
	STD*	827	348	622	462	367	682	404	572	589	626
SUMS	N	36	36	36	36	36	36	36	36	36	324
	MEAN*	3700	3958	4078	3948	3709	3810	3518	3834	3814	3819
	STD*	2057	1775	1658	1795	2056	1868	2076	1911	1804	1877
AVERAGE ARRAY 2											
1	N	12	12	12	12	12	12	12	12	12	108
	MEAN*[a]	547	619	700	632	500	699	622	725	773	646
	STD*	201	373	225	186	166	287	193	259	348	262
2	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	4325	4276	3908	4027	4311	4322	4830	4083	4126	4245
	STD*	262	396	445	559	483	613	327	1131	455	604
3	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	5028	4231	4158	4495	5062	4548	4996	4688	4660	4652
	STD*	827	348	622	462	367	682	404	572	589	626
SUMS	N	36	36	36	36	36	36	36	36	36	324
	MEAN*	3300	3042	2922	3052	3291	3190	3482	3166	3186	3181
	STD*	2057	1775	1658	1795	2056	1868	2076	1911	1804	1877

[a]MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE -3.

APPENDIX B

Key to Appendix B

Columns 1 through 9 correspond to the following fertilizer treatments: (nitrogen/phosphorus) 0/0, 0/275, 0/550, 550/550, 550/0, 1100/550, 1100/0, 550/275, and 1100/275.

Rows 1 through 13 correspond to the following sampling dates for the white oak litter bags: March through December 1971 (1-10) and January through March 1972 (11-13).

Rows 1 through 3 correspond to the following sampling dates for both red maple and black gum litter bags: March and September 1971 and March 1972.

N = The number of observations making up the mean.

STD = The standard deviation of the mean.

Table 15. Mean weight loss from white oak litter bags as a function of fertilizer treatment. Values are expressed as a percent of the original weight of leaf material.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
	N	12	12	12	12	12	12	12	12	12	108
1	MEAN*[a]	925	650	675	550	567	600	767	533	758	669
	STD*	191	385	377	378	405	400	352	326	284	358
	N	12	12	12	12	12	12	12	12	12	108
2	MEAN*	1267	1317	1225	1333	1350	1167	1558	1300	1417	1326
	STD*	287	644	245	342	193	250	337	319	233	345
	N	12	12	12	12	12	12	12	12	12	108
3	MEAN*	1000	842	750	667	958	808	1108	783	842	862
	STD*	292	466	555	470	491	483	444	413	540	468
	N	12	12	12	12	12	12	12	12	12	108
4	MEAN*	1242	1008	1092	1133	1433	1142	1400	1150	1267	1207
	STD*	429	555	511	573	458	462	522	514	667	523
	N	12	12	12	12	12	12	12	12	12	108
5	MEAN*	2092	1767	1350	1992	2142	1700	2150	1750	2050	1888
	STD*	380	502	558	414	403	367	523	489	444	508
	N	12	12	12	12	12	12	12	12	12	108
6	MEAN*	2550	2058	2075	2233	2500	2433	2750	2217	2575	2377
	STD*	448	552	403	832	503	569	579	651	494	595
	N	12	12	12	12	12	12	12	12	12	108
7	MEAN*	2867	2700	2492	2617	2950	2642	3083	2733	2783	2763
	STD*	326	234	239	356	355	315	237	466	295	354
	N	12	12	12	12	12	12	12	12	12	108
8	MEAN*	2417	2233	2142	2100	2375	2233	2717	2242	2425	2320
	STD*	338	412	427	316	355	178	255	432	384	383
	N	12	12	12	12	12	12	12	12	12	108
9	MEAN*	2892	2258	2367	2633	2783	2567	3108	2283	2533	2603
	STD*	355	278	436	250	453	412	414	286	339	444
	N	12	12	12	12	12	12	12	12	12	108
10	MEAN*	3075	2875	2458	2858	2817	2583	3142	2600	2967	2819
	STD*	505	283	365	481	666	386	365	400	460	483
	N	12	12	12	12	12	12	12	12	12	108
11	MEAN*	2983	2567	2475	2800	2767	2575	2967	2608	2917	2740
	STD*	229	257	293	457	320	234	206	297	269	335
	N	12	12	12	12	12	12	12	12	12	108
12	MEAN*	3258	2767	2567	2983	3275	2933	3283	2900	3300	3030
	STD*	312	267	337	569	490	940	295	266	570	539
	N	12	12	12	12	12	12	12	12	12	108
13	MEAN*	3392	2892	2708	3208	3108	2950	3217	2942	3250	3074
	STD*	530	512	470	882	360	309	901	863	470	637
	N	156	156	156	156	156	156	156	156	156	1404
SUMS	MEAN*	2304	1995	1875	2085	2233	2026	2404	2003	2237	2129
	STD*	938	879	819	997	942	910	967	909	954	937

[a] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE -2.

Table 16. Mean weight loss from red maple litter bags as a function of fertilizer treatment. Values are expressed as a percent of the original weight of leaf material.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
	N	12	12	12	12	12	12	12	12	12	108
1	MEAN*[a]	1150	1083	1225	1192	1317	1292	1200	1208	1308	1219
	STD*	387	217	267	303	469	162	191	382	219	302
	N	12	12	12	12	12	12	12	12	12	108
2	MEAN*	3250	2808	2900	2917	3367	3683	3092	3175	3258	3161
	STD*	412	1000	328	383	377	919	553	411	421	617
	N	12	12	12	12	12	12	12	12	12	108
3	MEAN*	3483	3125	2983	2683	3333	3300	3433	3308	3317	3219
	STD*	587	273	591	910	223	372	215	334	488	530
	N	36	36	36	36	36	36	36	36	36	324
SUMS	MEAN*	2628	2339	2369	2264	2672	2758	2575	2564	2628	2533
	STD*	1158	1087	917	968	1037	1204	1056	1040	1021	1056

[a]MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE -2.

Table 17. Mean weight loss from black gum litter bags as a function of fertilizer treatment. Values are expressed as a percent of the original weight of leaf material.

AVERAGE ARRAY 1

		1	2	3	4	5	6	7	8	9	SUMS
1	N	12	12	12	12	12	12	12	12	12	108
	MEAN*[a]	475	542	600	550	442	617	525	650	658	562
	STD*	171	318	204	157	138	244	171	243	297	227
2	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	3867	3733	3425	3550	3817	3825	4225	3583	3575	3733
	STD*	299	352	407	518	426	579	314	995	400	547
3	N	12	12	12	12	12	12	12	12	12	108
	MEAN*	4467	3733	3650	3925	4500	4000	4325	4100	4092	4088
	STD*	752	303	535	435	374	605	299	501	481	555
SUMS	N	36	36	36	36	36	36	36	36	36	324
	MEAN*	2936	2669	2558	2675	2919	2814	3025	2778	2775	2794
	STD*	1842	1558	1462	1580	1829	1651	1812	1668	1581	1655

[a]MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE -2.

APPENDIX C

Key to Appendix C

Columns 1 through 9 correspond to the following fertilizer treatments: (nitrogen/phosphorus) 0/0, 0/275, 0/550, 550/550, 550/0, 1100/550, 1100/0, 550/275, and 1100/275.

Rows 1 through 13 correspond to the following sampling dates for the white oak litter bags: March through December 1971 (1-10) and January through March 1972 (11-13).

Rows 1 through 3 correspond to the following sampling dates for both red maple and black gum litter bags: March and September 1971 and March 1972.

N = The number of observations making up the mean.

STD = The standard deviation of the mean.

Table 18. The mean concentrations of calcium (average array 1), sodium (average array 2), magnesium (average array 3), potassium (average array 4), phosphorus (average array 5), and nitrogen (average array 6) in white oak leaf litter as a function of fertilizer treatment and time.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[a]	626	631	635	629	641	622	555	617	615	619
	STD*	45	67	48	31	70	39	129	59	122	74
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	1914	1965	2173	2142	2073	2054	2024	2137	2146	2070
	STD*	177	317	585	510	245	460	126	133	55	325
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	1971	1851	1929	2088	2065	2274	2075	2097	2193	2060
	STD*	350	315	237	287	124	97	168	407	375	288
	N	6	6	6	6	6	6	6	6	6	54
4	MEAN*	772	535	854	900	793	736	498	507	1336	770
	STD*	576	44	550	595	609	579	79	49	807	533
	N	6	6	6	6	6	6	6	6	6	54
5	MEAN*	370	370	376	360	424	411	386	384	371	383
	STD*	30	55	40	21	76	70	66	54	46	53
	N	6	6	6	6	6	6	6	6	6	54
6	MEAN*	330	351	360	345	371	371	394	366	357	361
	STD*	36	23	32	28	30	46	54	24	18	36
	N	6	6	6	6	6	6	6	6	6	54
7	MEAN*	1527	1621	1893	1753	2081	1647	1589	1929	1593	1737
	STD*	597	634	202	735	217	1058	926	355	966	671
	N	6	6	6	6	6	6	6	6	6	54
8	MEAN*	1865	1848	2016	2193	2181	2349	2483	2177	2417	2170
	STD*	440	407	252	419	1055	731	119	339	644	556
	N	6	6	6	6	6	6	6	6	6	54
9	MEAN*	1932	1887	2073	2139	2268	2333	2507	2206	2218	2174
	STD*	333	259	203	194	218	453	171	377	499	349
	N	6	6	6	6	6	6	6	6	6	54
10	MEAN*	2043	2058	2090	2119	2260	2134	2561	2276	2471	2223
	STD*	334	373	136	314	315	384	148	406	120	329
	N	6	6	6	6	6	6	6	6	6	54
11	MEAN*	1868	1862	2026	2139	2158	2349	2446	2346	2359	2173
	STD*	348	366	277	414	111	314	263	456	157	360
	N	6	6	6	6	6	6	6	6	6	54
12	MEAN*	2103	2272	2077	2646	2423	2609	2675	2375	2834	2446
	STD*	400	162	319	549	240	602	207	418	289	433
	N	6	6	6	6	6	6	6	6	6	54
13	MEAN*	2372	2112	2233	2664	2453	2527	2646	2467	2538	2446
	STD*	614	335	81	278	184	377	395	142	93	344
	N	78	78	78	78	78	78	78	78	78	702
SUMS	MEAN*	1515	1489	1595	1701	1707	1724	1757	1683	1804	1664
	STD*	780	758	758	889	859	949	962	871	931	866

Table 18. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 2											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*[b]	1342	1181	1319	1247	1123	1230	1789	1417	1106	1306
	STD*	323	246	277	265	309	308	1443	579	114	562
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1373	1492	1362	1761	1534	1774	1399	1821	1437	1550
	STD*	344	814	465	417	268	567	310	728	214	492
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1287	1386	1481	1646	1379	1477	1689	1685	1565	1511
	STD*	361	296	313	443	250	289	201	348	320	326
4	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1122	908	1333	933	821	1080	951	871	1110	1014
	STD*	243	269	796	111	153	343	150	268	226	352
5	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1039	779	929	1255	1047	846	936	1033	993	984
	STD*	289	186	198	492	432	194	163	386	231	312
6	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	883	916	1054	935	936	997	1000	1096	1070	987
	STD*	126	190	532	182	160	148	142	423	285	266
7	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1239	1258	1304	1296	1838	1258	1186	1406	1504	1365
	STD*	192	129	115	405	816	296	369	499	618	449
8	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1306	1185	1445	1555	1333	1514	1147	1344	1416	1361
	STD*	333	113	280	551	378	536	217	562	185	378
9	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1481	1448	1456	2168	1660	1775	1585	1449	1444	1607
	STD*	116	295	235	882	211	494	477	197	248	445
10	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1765	1869	1878	1953	1821	2196	2278	2003	1852	1957
	STD*	135	238	223	201	219	1024	1009	499	275	523
11	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1610	1394	2123	1480	2332	1602	1788	1340	1909	1731
	STD*	415	230	835	208	1055	333	1199	275	735	710
12	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1643	1542	1446	1912	1520	1574	1649	1755	1629	1630
	STD*	98	351	329	501	446	490	811	333	450	444
13	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1728	1609	1919	1990	2194	1777	2168	1773	1880	1893
	STD*	387	619	406	653	960	549	1254	448	520	671
SUMS	N	78	78	78	78	78	78	78	78	78	702
	MEAN*	1371	1305	1465	1549	1503	1469	1505	1461	1455	1454
	STD*	366	447	518	573	660	572	816	525	466	564

Table 18. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 3											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	256	269	319	275	263	269	262	234	262	268
	STD*	56	88	73	48	86	64	89	114	81	77
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	633	496	486	563	787	699	721	599	608	621
	STD*	28	119	105	82	154	206	143	106	37	147
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	681	405	389	552	768	748	849	485	697	619
	STD*	156	123	111	100	212	262	78	140	192	218
4	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	261	163	178	286	405	277	441	162	420	288
	STD*	132	61	92	108	227	85	164	47	173	162
5	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	120	110	90	126	184	166	237	111	118	140
	STD*	35	61	12	41	101	67	117	37	41	75
6	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	98	86	93	130	198	120	209	100	141	130
	STD*	18	26	28	38	60	32	65	26	48	57
7	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	547	493	487	569	899	505	819	649	573	616
	STD*	196	289	47	262	298	380	561	109	358	321
8	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	660	624	508	663	774	880	1151	771	828	762
	STD*	146	224	62	86	237	398	265	290	228	280
9	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	889	756	602	796	1155	871	1101	993	884	894
	STD*	266	293	141	171	384	313	117	253	407	304
10	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1037	1007	636	921	1324	1089	1316	1095	996	1047
	STD*	281	340	96	312	450	391	253	211	287	345
11	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	784	777	650	719	1047	964	1175	954	905	886
	STD*	169	295	225	202	322	375	273	333	263	304
12	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1095	1204	752	1280	1454	1262	1434	1307	1196	1220
	STD*	166	219	106	320	501	371	245	479	400	369
13	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1044	980	771	1162	1676	1500	1166	1440	998	1193
	STD*	311	294	203	236	560	524	357	383	316	440
SUMS	N	78	78	78	78	78	78	78	78	78	702
	MEAN*	623	567	458	618	841	719	837	685	663	668
	STD*	376	403	249	390	553	506	476	492	408	449

Table 18. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 4											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*	421	420	471	421	406	457	411	426	448	431
	STD*	96	78	117	83	74	37	123	69	115	87
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	603	348	304	456	561	628	562	482	453	489
	STD*	93	91	83	115	93	376	195	130	70	186
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	741	390	353	554	761	594	863	622	800	631
	STD*	120	77	117	144	255	163	166	106	123	218
	N	6	6	6	6	6	6	6	6	6	54
4	MEAN*	568	308	240	344	625	413	520	332	576	436
	STD*	143	134	75	139	157	107	80	87	168	176
	N	6	6	6	6	6	6	6	6	6	54
5	MEAN*	330	217	147	275	439	273	386	291	356	302
	STD*	80	27	43	40	88	59	94	33	88	104
	N	6	6	6	6	6	6	6	6	6	54
6	MEAN*	448	327	367	343	468	421	493	469	512	428
	STD*	78	98	68	134	38	78	150	112	39	109
	N	6	6	6	6	6	6	6	6	6	54
7	MEAN*	676	577	562	736	749	627	526	737	685	653
	STD*	177	177	90	281	155	293	198	72	315	211
	N	6	6	6	6	6	6	6	6	6	54
8	MEAN*	758	744	710	927	723	950	780	1028	849	830
	STD*	186	189	130	229	218	290	103	505	204	257
	N	6	6	6	6	6	6	6	6	6	54
9	MEAN*	1147	1036	882	1147	1118	1229	930	1340	1106	1104
	STD*	185	244	269	415	199	322	113	138	349	279
	N	6	6	6	6	6	6	6	6	6	54
10	MEAN*	947	1038	988	994	1166	1029	937	1042	1081	1025
	STD*	142	98	227	211	224	251	161	211	81	185
	N	6	6	6	6	6	6	6	6	6	54
11	MEAN*	169	136	270	189	379	213	405	182	283	247
	STD*	51	38	187	69	314	65	416	60	196	205
	N	6	6	6	6	6	6	6	6	6	54
12	MEAN*	912	749	802	990	720	811	577	865	948	819
	STD*	183	148	204	177	148	221	89	145	167	197
	N	6	6	6	6	6	6	6	6	6	54
13	MEAN*	716	612	675	738	696	714	676	758	670	695
	STD*	113	100	234	129	192	213	223	151	204	170
	N	78	78	78	78	78	78	78	78	78	702
SUMS	MEAN*	649	531	521	624	678	643	621	659	674	622
	STD*	287	307	299	354	291	353	255	369	311	319

Table 18. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 5											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[c]	1043	1066	954	1003	1019	1007	829	1053	967	994
	STD*	419	177	149	252	303	319	324	283	210	269
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	519	810	1090	1253	435	1284	383	825	842	827
	STD*	46	680	292	477	40	673	44	131	118	471
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	486	752	831	1229	488	1012	373	1105	1052	814
	STD*	87	508	105	568	31	553	80	692	518	493
	N	6	6	6	6	6	6	6	6	6	54
4	MEAN*	1122	887	708	879	540	1154	456	842	861	828
	STD*	352	245	117	557	272	736	161	200	328	414
	N	6	6	6	6	6	6	6	6	6	54
5	MEAN*	564	499	1009	787	390	739	312	506	453	584
	STD*	198	220	575	383	131	251	41	153	61	328
	N	6	6	6	6	6	6	6	6	6	54
6	MEAN*	563	689	613	978	382	606	405	571	511	591
	STD*	192	214	203	549	198	186	195	140	126	286
	N	6	6	6	6	6	6	6	6	6	54
7	MEAN*	660	824	1113	1887	635	916	389	1287	1330	1004
	STD*	312	444	454	1752	75	720	292	345	1123	843
	N	6	6	6	6	6	6	6	6	6	54
8	MEAN*	1962	2560	2423	2773	1547	4249	1552	2115	2332	2390
	STD*	1892	1699	2499	2088	1392	4268	1180	1700	1452	2171
	N	6	6	6	6	6	6	6	6	6	54
9	MEAN*	931	1050	1295	1290	804	2032	705	1272	1271	1183
	STD*	230	241	694	307	66	1820	118	436	271	736
	N	6	6	6	6	6	6	6	6	6	54
10	MEAN*	864	1030	1448	1345	821	1351	786	1215	1500	1151
	STD*	77	357	617	545	157	449	273	399	546	468
	N	6	6	6	6	6	6	6	6	6	54
11	MEAN*	941	1155	1152	1977	816	2252	832	1338	1603	1341
	STD*	112	400	85	872	134	1449	85	363	700	763
	N	6	6	6	6	6	6	6	6	6	54
12	MEAN*	2299	1735	2199	3994	801	2289	812	1837	1882	1983
	STD*	3339	1219	1673	3172	100	1516	167	948	805	1892
	N	6	6	6	6	6	6	6	6	6	54
13	MEAN*	840	914	1301	3047	746	1421	766	1599	1178	1312
	STD*	99	208	394	2886	57	387	78	789	243	1162
	N	78	78	78	78	78	78	78	78	78	702
SUMS	MEAN*	984	1075	1241	1726	725	1562	662	1197	1214	1154
	STD*	1131	805	982	1656	489	1650	472	756	783	1098

Table 18. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 6											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[a]	955	953	930	1007	892	1010	942	861	925	942
	STD*	54	90	136	129	119	271	83	63	143	133
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	1243	1316	1248	1603	1946	2071	2591	1706	1862	1732
	STD*	330	477	324	448	420	693	579	637	440	624
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	1465	1304	1337	1824	1852	1436	2259	1556	1718	1639
	STD*	629	338	338	583	488	371	476	298	384	505
	N	6	6	6	6	6	6	6	6	6	54
4	MEAN*	1566	1263	1273	1664	1673	1625	1964	1440	1735	1578
	STD*	629	416	435	434	627	483	878	346	623	561
	N	6	6	6	6	6	6	6	6	6	54
5	MEAN*	1974	1709	1600	2018	2335	1740	2241	1814	2282	1968
	STD*	820	757	464	710	871	595	669	470	521	667
	N	6	6	6	6	6	6	6	6	6	54
6	MEAN*	1199	1098	1086	1375	1339	1387	1678	1320	1480	1329
	STD*	261	178	129	89	214	190	344	143	165	258
	N	6	6	6	6	6	6	6	6	6	54
7	MEAN*	1333	1328	1522	1654	1767	1538	1688	1418	1784	1559
	STD*	263	89	479	406	298	326	255	98	205	319
	N	6	6	6	6	6	6	6	6	6	54
8	MEAN*	1524	1527	1224	1562	1775	1547	2047	1587	1572	1596
	STD*	212	266	190	155	151	245	191	183	429	304
	N	6	6	6	6	6	6	6	6	6	54
9	MEAN*	1932	1561	1488	1641	1891	1803	2057	1877	1859	1790
	STD*	383	235	131	198	156	224	162	260	252	279
	N	6	6	6	6	6	6	6	6	6	54
10	MEAN*	1700	1358	1249	1660	1786	1574	1958	1563	1820	1630
	STD*	236	132	80	220	154	134	198	256	140	270
	N	6	6	6	6	6	6	6	6	6	54
11	MEAN*	1704	1593	1350	1806	1827	1710	1974	1524	1829	1702
	STD*	142	616	125	232	173	127	216	122	166	299
	N	6	6	6	6	6	6	6	6	6	54
12	MEAN*	1789	1657	1443	1809	1790	1706	2157	1613	2036	1778
	STD*	197	208	140	176	284	140	161	119	153	264
	N	6	6	6	6	6	6	6	6	6	54
13	MEAN*	1647	1510	1339	1877	1781	1688	1942	1703	1855	1705
	STD*	122	175	91	225	213	186	211	326	107	256
	N	78	78	78	78	78	78	78	78	78	702
SUMS	MEAN*	1541	1398	1315	1654	1743	1603	1961	1537	1750	1611
	STD*	464	398	308	410	479	404	532	371	431	462

[a] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 1.

[b] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE -1.

[c] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 0.

Table 19. The mean concentrations of calcium (average array 1), sodium (average array 2), magnesium (average array 3), potassium (average array 4), phosphorus (average array 5), and nitrogen (average array 6) in red maple leaf litter as a function of fertilizer treatment and time.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*[a]	1119	1287	1303	1344	1224	1290	1369	1372	1223	1281
	STD*	244	131	164	180	154	220	164	156	131	179
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1111	1175	1311	1548	1347	1416	1453	1443	1729	1392
	STD*	77	264	181	235	141	157	144	298	358	271
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1307	1403	1322	1719	1493	1888	1574	1551	1660	1546
	STD*	92	115	161	132	189	387	137	92	511	290
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	1179	1288	1312	1537	1355	1531	1465	1455	1537	1407
	STD*	174	197	159	236	190	369	164	204	416	273
AVERAGE ARRAY 2											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*[b]	1414	1503	1514	1558	2012	1448	1477	1456	1258	1516
	STD*	428	228	307	389	476	89	157	629	242	388
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1431	1719	1539	1475	1385	1858	1363	2012	1539	1591
	STD*	347	844	313	281	200	742	333	999	357	560
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	2068	1990	2209	3031	1881	2135	1991	1919	1768	2110
	STD*	434	287	247	2455	384	780	908	237	303	942
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	1638	1737	1754	2021	1759	1814	1610	1796	1522	1739
	STD*	492	540	429	1543	446	654	601	699	357	718

Table 19. (Continued)

AVERAGE ARRAY 3

		1	2	3	4	5	6	7	8	9	SUMS
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[c]	750	865	905	935	864	937	977	891	784	879
	STD*	141	227	278	103	80	222	138	195	120	179
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	1071	665	882	955	1648	1134	1526	1103	1273	1140
	STD*	306	142	340	260	604	202	306	413	500	448
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	1124	1139	791	1326	1376	1478	1178	1466	997	1208
	STD*	309	192	170	384	395	450	197	470	479	395
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	982	890	859	1072	1296	1183	1227	1153	1018	1076
	STD*	301	268	261	317	517	373	315	431	433	385

AVERAGE ARRAY 4

		1	2	3	4	5	6	7	8	9	SUMS
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[b]	5546	6454	7055	6140	6220	6783	6360	6255	6744	6395
	STD*	1316	1020	1491	584	561	1266	594	1384	996	1080
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	5020	6251	4859	6064	5543	6596	5328	5580	6164	5712
	STD*	1921	3102	1643	2713	1767	3998	2414	2331	2522	2447
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	6516	6574	6017	8369	7206	7384	5680	7734	7120	6956
	STD*	788	1058	962	1627	881	2175	1434	1868	2938	1734
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	5694	6426	5977	6857	6323	6921	5789	6523	6676	6354
	STD*	1478	1867	1604	2063	1317	2585	1618	2011	2206	1899

Table 19. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 5											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[c]	420	456	470	433	446	431	421	457	444	442
	STD*	129	53	38	46	41	35	34	28	54	56
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	847	1487	1591	2670	817	2609	693	2133	2531	1709
	STD*	144	955	1926	2187	116	1087	36	1895	1765	1492
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	810	1325	1360	3535	832	3717	760	1402	1558	1700
	STD*	51	630	301	1838	46	4293	58	481	640	1823
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	693	1089	1140	2213	698	2252	625	1331	1511	1283
	STD*	227	776	1168	2052	197	2782	156	1274	1345	1478
AVERAGE ARRAY 6											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[a]	1124	1115	1412	971	1016	918	1031	1754	1070	1157
	STD*	217	276	965	173	287	259	291	1614	390	669
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	1307	1286	1466	1431	1330	1533	1606	1477	1478	1435
	STD*	130	129	460	100	596	75	295	145	270	293
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	1550	1488	1592	1665	1800	1673	2015	1722	1722	1692
	STD*	91	106	516	324	104	111	81	119	375	275
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	1327	1297	1490	1356	1382	1375	1551	1651	1423	1428
	STD*	231	235	648	361	492	373	474	891	429	499

[a]MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 1.

[b]MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE -1.

[c]MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 0.

Table 20. The mean concentrations of calcium (average array 1), sodium (average array 2), magnesium (average array 3), potassium (average array 4), phosphorus (average array 5), and nitrogen (average array 6) in black gum leaf litter as a function of fertilizer treatment and time.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN* [a]	1381	1601	1477	1381	1614	1502	1549	1620	1451	1508
	STD*	174	115	183	190	181	214	81	483	173	227
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1639	1825	1983	2384	1884	2071	2072	2086	2440	2043
	STD*	175	153	544	411	155	252	209	475	195	380
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	2086	2028	2132	2164	2133	2491	2274	2245	2206	2195
	STD*	238	266	422	272	321	371	239	226	236	301
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	1702	1818	1864	1976	1877	2022	1965	1984	2032	1915
	STD*	353	253	482	527	307	497	361	473	474	426
AVERAGE ARRAY 2											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN* [b]	1436	1067	1342	1591	1295	1582	1265	1744	1273	1400
	STD*	279	169	147	619	210	393	203	560	291	385
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1309	1227	1746	1615	1342	1424	1748	1482	1558	1495
	STD*	349	210	477	503	219	449	733	483	396	451
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1606	1665	2349	1938	1928	2021	1903	2013	1730	1906
	STD*	464	235	760	385	287	427	436	548	324	470
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	1450	1320	1812	1715	1522	1676	1638	1747	1520	1600
	STD*	371	324	651	507	373	475	552	547	373	487

Table 20. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 3											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*[c]	2679	2789	2774	2839	2505	2756	2946	2922	2622	2759
	STD*	359	262	309	473	636	381	371	711	561	457
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1397	1133	938	1322	1654	1284	1717	1306	1421	1353
	STD*	294	163	183	333	214	326	413	290	416	362
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	1573	1505	1184	1531	1712	1869	1627	1902	1116	1558
	STD*	435	339	391	442	703	532	189	403	224	473
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	1883	1809	1632	1897	1957	1970	2096	2043	1720	1890
	STD*	678	771	885	795	661	738	696	832	778	757
AVERAGE ARRAY 4											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*[c]	776	641	589	863	631	711	724	696	656	699
	STD*	231	110	62	279	98	242	142	132	118	177
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	784	829	771	1077	809	981	734	863	1038	876
	STD*	57	120	118	182	163	144	101	192	132	175
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	831	883	1116	1191	1132	1198	920	1104	959	1037
	STD*	287	479	365	465	478	349	266	818	318	438
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	797	784	825	1043	857	964	792	888	884	871
	STD*	204	294	308	340	351	318	196	493	260	321

Table 20. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 5											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[c]	555	483	523	580	538	519	523	626	542	543
	STD*	67	55	71	69	116	106	73	108	75	88
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	1368	1415	5822	5601	975	2076	937	3329	3600	2791
	STD*	519	278	4851	4615	156	289	135	2864	1347	2919
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	1056	1417	3580	3202	989	4844	1033	3257	1871	2361
	STD*	73	382	3011	2884	107	3463	110	2689	510	2295
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	993	1105	3308	3128	834	2480	831	2404	2004	1899
	STD*	448	521	3819	3628	247	2635	250	2493	1507	2344
AVERAGE ARRAY 6											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[a]	993	892	963	996	987	1009	958	990	976	974
	STD*	104	139	87	124	162	108	62	106	59	107
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	2233	2172	1683	1894	1918	1927	1916	1752	1864	1929
	STD*	1015	1039	313	497	312	388	300	296	409	562
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	1956	1759	1755	2056	2067	2178	2477	2110	2240	2066
	STD*	378	81	213	142	381	132	234	117	327	315
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	1727	1608	1467	1649	1657	1704	1784	1617	1693	1656
	STD*	804	792	424	560	567	566	678	514	616	615

[a] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 1.

[b] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE -1.

[c] MULTIPLY MEANS AND STANIARD DEVIATIONS BY 10 TO THE 0.

APPENDIX D

Key to Appendix D

Columns 1 through 9 correspond to the following fertilizer treatments: (nitrogen/phosphorus) 0/0, 0/275, 0/550, 550/550, 550/0, 1100/550, 1100/0, 550/275, and 1100/275.

Rows 1 through 13 correspond to the following sampling dates for the white oak litter bags: March through December 1971 (1-10) and January through March 1972 (11-13).

Rows 1 through 3 correspond to the following sampling dates for both red maple and black gum litter bags: March and September 1971 and March 1972.

N = The number of observations making up the mean.

STD = The standard deviation of the mean.

Table 21. The mean weights of calcium (average array 1), sodium (average array 2), magnesium (average array 3), potassium (average array 4), phosphorus (average array 5), and nitrogen (average array 6) in white oak leaf litter as a function of fertilizer treatment and time.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[a]	375	375	396	410	393	380	339	393	379	382
	STD*	28	33	48	18	81	36	80	42	72	53
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	1065	1085	1179	1147	1111	1177	1041	1171	1123	1122
	STD*	107	211	305	283	157	298	58	104	83	191
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	1147	1098	1172	1322	1219	1386	1201	1345	1403	1255
	STD*	245	158	132	266	158	147	185	277	249	220
	N	6	6	6	6	6	6	6	6	6	54
4	MEAN*	446	329	497	518	417	413	277	297	731	436
	STD*	339	49	321	315	280	282	38	41	368	275
	N	6	6	6	6	6	6	6	6	6	54
5	MEAN*	173	186	206	178	192	204	183	198	179	189
	STD*	15	44	26	14	27	25	39	24	19	28
	N	6	6	6	6	6	6	6	6	6	54
6	MEAN*	137	167	167	164	160	159	162	171	146	159
	STD*	15	25	27	48	14	32	31	26	24	28
	N	6	6	6	6	6	6	6	6	6	54
7	MEAN*	559	625	763	683	749	620	588	758	600	661
	STD*	194	257	103	292	67	419	355	110	372	260
	N	6	6	6	6	6	6	6	6	6	54
8	MEAN*	721	758	892	1004	869	1022	974	923	927	899
	STD*	180	153	230	223	401	297	62	135	184	231
	N	6	6	6	6	6	6	6	6	6	54
9	MEAN*	704	848	832	855	836	935	869	962	879	858
	STD*	87	136	145	57	148	204	155	191	224	161
	N	6	6	6	6	6	6	6	6	6	54
10	MEAN*	685	738	876	706	792	794	825	838	852	789
	STD*	102	142	92	189	170	153	67	196	223	157
	N	6	6	6	6	6	6	6	6	6	54
11	MEAN*	648	755	777	781	819	904	857	958	820	813
	STD*	85	171	154	137	91	193	116	171	123	156
	N	6	6	6	6	6	6	6	6	6	54
12	MEAN*	681	866	826	1032	760	1054	837	865	808	859
	STD*	116	140	156	346	121	322	85	154	279	226
	N	6	6	6	6	6	6	6	6	6	54
13	MEAN*	734	827	861	985	830	871	929	942	768	861
	STD*	141	148	37	245	34	196	150	72	131	154
	N	78	78	78	78	78	78	78	78	78	702
SUMS	MEAN*	621	666	726	753	704	763	699	756	740	714
	STD*	319	329	347	401	349	426	361	384	393	370

Table 21. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 2											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN* b	804	700	815	816	695	763	1056	908	684	805
	STD*	191	130	154	199	260	251	780	385	71	329
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	760	822	738	939	819	1027	717	980	753	839
	STD*	173	436	242	208	140	396	139	327	127	269
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	744	830	903	1049	816	910	977	1078	1011	924
	STD*	217	193	188	356	195	241	182	221	258	241
4	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	647	559	758	552	448	630	532	507	657	587
	STD*	142	170	387	72	68	214	97	154	210	198
5	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	484	385	512	622	474	423	440	545	480	485
	STD*	127	92	135	252	176	101	71	249	110	161
6	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	365	443	479	425	401	423	407	504	426	431
	STD*	44	153	220	44	56	76	58	173	73	115
7	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	458	483	526	503	663	465	432	564	581	519
	STD*	47	65	71	161	286	122	152	222	285	179
8	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	506	492	643	710	537	657	445	576	553	569
	STD*	147	80	218	239	159	209	49	262	101	183
9	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	543	651	585	861	613	720	557	632	571	637
	STD*	42	147	135	327	124	235	218	101	115	191
10	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	602	674	790	643	646	842	731	739	632	700
	STD*	120	123	141	118	167	482	310	207	169	228
11	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	559	564	821	540	877	618	614	552	645	643
	STD*	112	97	373	53	386	170	381	129	185	254
12	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	534	580	577	748	487	630	527	645	465	577
	STD*	32	124	147	269	197	194	310	150	203	199
13	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	546	634	743	767	733	592	761	684	561	669
	STD*	131	262	177	391	276	133	451	203	158	258
SUMS	N	78	78	78	78	78	78	78	78	78	702
	MEAN*	581	601	684	706	632	669	630	686	617	645
	STD*	172	215	240	278	245	285	353	277	214	260

Table 21. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 3											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN* b	1538	1624	1969	1788	1592	1637	1601	1482	1623	1650
	STD*	341	613	404	302	484	403	574	688	512	477
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	3524	2715	2652	3014	4205	4031	3715	3257	3179	3366
	STD*	205	597	623	486	830	1347	771	401	300	827
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	3946	2380	2344	3492	4531	4578	4900	3118	4465	3750
	STD*	971	595	584	840	1306	1677	666	942	1307	1335
	N	6	6	6	6	6	6	6	6	6	54
4	MEAN*	1514	1012	1039	1701	2189	1590	2496	948	2393	1654
	STD*	780	413	541	652	1141	394	1034	286	764	875
	N	6	6	6	6	6	6	6	6	6	54
5	MEAN*	565	570	498	628	842	818	1130	571	578	689
	STD*	184	364	120	226	447	307	581	167	239	356
	N	6	6	6	6	6	6	6	6	6	54
6	MEAN*	405	415	422	648	845	521	863	467	597	575
	STD*	72	175	113	343	232	184	324	144	271	267
	N	6	6	6	6	6	6	6	6	6	54
7	MEAN*	2020	1927	1968	2226	3212	1926	3064	2549	2199	2344
	STD*	702	1243	290	1064	956	1569	2198	318	1479	1232
	N	6	6	6	6	6	6	6	6	6	54
8	MEAN*	2576	2537	2229	3028	3151	3801	4469	3297	3157	3138
	STD*	786	850	451	431	1156	1598	762	1371	581	1104
	N	6	6	6	6	6	6	6	6	6	54
9	MEAN*	3222	3406	2411	3175	4332	3471	3776	4340	3557	3521
	STD*	856	1388	674	603	1779	1265	476	1209	1836	1256
	N	6	6	6	6	6	6	6	6	6	54
10	MEAN*	3475	3584	2677	3012	4435	4027	4204	4025	3564	3667
	STD*	893	1155	536	986	928	1348	606	925	1777	1131
	N	6	6	6	6	6	6	6	6	6	54
11	MEAN*	2739	3141	2537	2607	3908	3731	4117	3875	3157	3312
	STD*	565	1217	1051	609	1034	1654	1042	1256	1068	1168
	N	6	6	6	6	6	6	6	6	6	54
12	MEAN*	3550	4620	2972	4916	4470	4978	4445	4767	3448	4241
	STD*	467	1166	328	1332	1228	1317	555	1799	1685	1309
	N	6	6	6	6	6	6	6	6	6	54
13	MEAN*	3178	3841	2988	4249	5640	5211	4103	5441	2969	4180
	STD*	527	1210	893	1098	1729	2076	1302	1177	871	1549
	N	78	78	78	78	78	78	78	78	78	702
SUMS	MEAN*	2461	2444	2054	2652	3335	3102	3299	2934	2683	2776
	STD*	1274	1516	991	1406	1798	1957	1578	1808	1533	1608

Table 21. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 4											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN* b	2522	2508	2893	2759	2495	2781	2484	2711	2776	2659
	STD*	581	517	595	626	613	166	676	405	754	547
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	3363	1922	1667	2444	2992	3599	2895	2629	2367	2653
	STD*	604	551	500	660	471	2135	1024	664	380	1047
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	4294	2329	2158	3528	4525	3676	4999	3991	5132	3848
	STD*	749	494	813	1193	1571	1333	1122	759	858	1389
	N	6	6	6	6	6	6	6	6	6	54
4	MEAN*	3277	1975	1401	1996	3409	2386	2933	1961	3264	2500
	STD*	871	805	447	679	734	559	651	599	544	933
	N	6	6	6	6	6	6	6	6	6	54
5	MEAN*	1556	1084	805	1356	2018	1356	1799	1504	1717	1466
	STD*	425	210	242	179	498	241	338	133	380	457
	N	6	6	6	6	6	6	6	6	6	54
6	MEAN*	1870	1521	1682	1497	2020	1795	1978	2167	2081	1846
	STD*	379	364	236	304	240	422	459	456	259	401
	N	6	6	6	6	6	6	6	6	6	54
7	MEAN*	2526	2231	2272	2876	2688	2348	1928	2958	2598	2492
	STD*	758	790	452	1169	486	1213	797	685	1232	877
	N	6	6	6	6	6	6	6	6	6	54
8	MEAN*	2934	3053	3141	4238	2888	4131	3061	4415	3237	3455
	STD*	786	772	866	1131	829	1196	448	2373	459	1192
	N	6	6	6	6	6	6	6	6	6	54
9	MEAN*	4179	4648	3563	4556	4141	4916	3189	5844	4423	4384
	STD*	477	1153	1340	1517	1024	1288	409	769	1660	1286
	N	6	6	6	6	6	6	6	6	6	54
10	MEAN*	3223	3755	4138	3277	4029	3842	3001	3852	3680	3651
	STD*	655	681	1247	891	767	1014	417	996	753	878
	N	6	6	6	6	6	6	6	6	6	54
11	MEAN*	588	551	1065	690	1407	828	1376	741	944	910
	STD*	142	161	799	249	1170	310	1344	231	549	710
	N	6	6	6	6	6	6	6	6	6	54
12	MEAN*	2972	2872	3172	3824	2255	3183	1794	3158	2735	2885
	STD*	619	796	737	889	497	664	211	573	1035	856
	N	6	6	6	6	6	6	6	6	6	54
13	MEAN*	2237	2415	2610	2791	2368	2459	2377	2918	2031	2467
	STD*	265	550	928	1059	741	861	819	721	738	758
	N	78	78	78	78	78	78	78	78	78	702
SUMS	MEAN*	2734	2367	2356	2756	2864	2869	2601	2988	2845	2709
	STD*	1136	1206	1218	1389	1171	1471	1130	1523	1328	1303

Table 21. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 5											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[c]	623	633	595	651	623	626	501	675	598	614
	STD*	247	94	119	157	204	244	177	199	133	174
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	289	456	592	684	232	742	197	452	440	454
	STD*	30	410	161	306	18	418	25	80	59	280
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	282	458	509	793	286	643	215	712	683	509
	STD*	59	328	92	430	15	414	46	452	364	343
	N	6	6	6	6	6	6	6	6	6	54
4	MEAN*	646	546	410	507	296	662	254	500	499	480
	STD*	207	172	52	285	162	412	92	159	181	239
	N	6	6	6	6	6	6	6	6	6	54
5	MEAN*	264	255	579	393	177	372	147	259	219	296
	STD*	93	124	380	210	59	139	13	66	30	197
	N	6	6	6	6	6	6	6	6	6	54
6	MEAN*	234	334	282	508	167	255	171	269	202	269
	STD*	84	144	88	393	94	69	97	85	19	175
	N	6	6	6	6	6	6	6	6	6	54
7	MEAN*	243	322	456	743	228	342	145	526	509	391
	STD*	113	193	222	699	22	274	109	228	453	345
	N	6	6	6	6	6	6	6	6	6	54
8	MEAN*	749	1006	1152	1332	594	1804	617	888	892	1004
	STD*	709	605	1359	1164	507	1746	478	720	523	962
	N	6	6	6	6	6	6	6	6	6	54
9	MEAN*	337	470	533	519	298	841	241	560	504	478
	STD*	63	107	341	131	60	812	40	216	126	333
	N	6	6	6	6	6	6	6	6	6	54
10	MEAN*	293	372	629	442	282	509	250	453	530	418
	STD*	47	140	321	171	36	203	74	183	259	208
	N	6	6	6	6	6	6	6	6	6	54
11	MEAN*	329	466	439	728	308	886	290	550	558	506
	STD*	35	159	49	343	45	619	15	154	250	308
	N	6	6	6	6	6	6	6	6	6	54
12	MEAN*	738	687	921	1638	250	906	256	672	554	736
	STD*	1063	564	779	1532	30	560	72	353	329	790
	N	6	6	6	6	6	6	6	6	6	54
13	MEAN*	265	362	504	1292	254	489	269	620	353	490
	STD*	43	104	165	1442	31	154	30	324	82	556
	N	78	78	78	78	78	78	78	78	78	702
SUMS	MEAN*	407	490	585	787	307	698	273	549	503	511
	STD*	391	332	490	773	203	691	193	325	302	478

Table 21. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 6											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN* [a]	572	569	579	655	545	623	576	549	571	582
	STD*	32	78	102	70	94	208	80	53	84	98
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	694	717	677	861	1040	1193	1336	927	978	936
	STD*	194	245	170	253	223	455	313	327	261	340
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	861	773	817	1152	1089	881	1302	997	1102	997
	STD*	411	190	212	433	299	282	279	201	253	321
	N	6	6	6	6	6	6	6	6	6	54
4	MEAN*	903	784	750	1004	938	954	1121	836	1019	923
	STD*	370	280	285	356	423	323	568	183	423	361
	N	6	6	6	6	6	6	6	6	6	54
5	MEAN*	931	856	896	999	1071	871	1059	935	1113	970
	STD*	408	435	336	358	428	307	319	222	295	336
	N	6	6	6	6	6	6	6	6	6	54
6	MEAN*	500	515	502	654	574	590	686	611	612	583
	STD*	120	63	67	193	77	104	158	63	156	128
	N	6	6	6	6	6	6	6	6	6	54
7	MEAN*	502	509	611	644	639	564	603	561	678	590
	STD*	124	52	190	187	127	118	51	42	90	126
	N	6	6	6	6	6	6	6	6	6	54
8	MEAN*	589	635	533	716	717	674	801	675	607	661
	STD*	97	157	96	106	119	90	57	92	171	130
	N	6	6	6	6	6	6	6	6	6	54
9	MEAN*	705	699	597	657	698	722	712	816	738	705
	STD*	113	109	98	77	120	98	124	105	139	116
	N	6	6	6	6	6	6	6	6	6	54
10	MEAN*	591	487	523	555	627	587	627	578	623	578
	STD*	203	54	49	148	119	77	29	138	151	121
	N	6	6	6	6	6	6	6	6	6	54
11	MEAN*	596	652	515	660	692	655	694	625	629	635
	STD*	42	285	74	70	78	97	105	61	38	120
	N	6	6	6	6	6	6	6	6	6	54
12	MEAN*	581	631	573	695	560	689	676	589	582	620
	STD*	55	121	68	104	99	152	82	56	195	116
	N	6	6	6	6	6	6	6	6	6	54
13	MEAN*	522	594	516	691	603	578	682	646	561	599
	STD*	82	107	27	172	74	108	85	96	101	111
	N	78	78	78	78	78	78	78	78	78	702
SUMS	MEAN*	657	648	622	765	753	737	836	719	755	721
	STD*	248	215	194	271	279	270	335	208	281	265

[a] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 2.

[b] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 0.

[c] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 1.

Table 22. The mean weights of calcium (average array 1), sodium (average array 2), magnesium (average array 3), potassium (average array 4), phosphorus (average array 5), and nitrogen (average array 6) in red maple leaf litter as a function of fertilizer treatment and time.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[a]	6450	7541	7318	7671	6641	7027	7622	7573	6760	7178
	STD*	1498	896	888	855	901	1608	1013	1396	868	1141
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	3566	4700	4503	5846	4340	4174	4416	4752	5719	4669
	STD*	510	438	930	1458	294	1724	678	1165	1612	1225
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	3720	4524	4601	5980	4546	6034	4737	4802	4975	4880
	STD*	1310	672	673	1040	630	1932	622	520	1575	1231
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	4579	5588	5474	6499	5176	5745	5592	5709	5818	5576
	STD*	1761	1565	1556	1374	1235	2053	1659	1701	1511	1650
AVERAGE ARRAY 2											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[b]	804	882	852	888	1094	784	823	776	695	844
	STD*	209	158	178	212	274	64	106	258	144	204
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	463	707	528	552	447	588	407	646	505	538
	STD*	142	320	126	133	58	418	66	262	129	220
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	604	638	768	1073	569	692	584	594	556	675
	STD*	260	102	101	929	101	346	211	90	243	370
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	623	742	716	838	703	688	605	672	585	686
	STD*	244	227	192	567	331	308	220	220	188	301

Table 22. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 3											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[b]	4320	5081	5054	5346	4690	5115	5425	4862	4340	4915
	STD*	870	1410	1406	538	536	1511	689	975	742	1022
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	3550	2698	3076	3576	5250	3286	4721	3665	4224	3783
	STD*	1462	452	1458	1117	1493	1234	1428	1564	1849	1495
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	2990	3688	2728	4496	4197	4672	3546	4502	3075	3766
	STD*	874	840	485	918	1230	1638	703	1394	1561	1258
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	3620	3822	3619	4472	4713	4358	4564	4343	3879	4155
	STD*	1179	1365	1545	1119	1175	1597	1233	1355	1493	1375
AVERAGE ARRAY 4											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[b]	3198	3786	3953	3527	3380	3693	3533	3390	3725	3576
	STD*	821	670	760	486	412	881	276	563	587	626
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	1565	2426	1658	2265	1810	2038	1589	1832	2078	1918
	STD*	445	1029	560	1016	620	1550	633	767	1047	888
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	1877	2124	2081	2918	2197	2385	1704	2410	2242	2215
	STD*	723	457	278	770	319	1003	438	647	1210	736
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	2213	2779	2564	2903	2462	2705	2275	2544	2692	2570
	STD*	970	1029	1157	910	816	1330	1018	910	1198	1045

Table 22. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 5											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*[a]	242	266	264	249	242	234	234	251	245	248
	STD*	77	24	26	41	27	31	18	29	30	36
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	270	583	608	1034	267	786	212	722	862	594
	STD*	46	322	843	907	59	535	38	688	633	584
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	233	436	474	1279	253	1273	228	434	489	566
	STD*	90	248	112	770	9	1639	19	151	250	694
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	248	428	449	854	254	764	225	469	532	469
	STD*	71	258	484	788	37	1032	27	431	453	544
AVERAGE ARRAY 6											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*[a]	6575	6550	8081	5602	5565	5022	5748	9070	5902	6457
	STD*	1815	1747	5888	1258	1830	1726	1700	7035	2105	3398
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	4184	5526	5038	5377	4414	4458	4911	4857	4866	4848
	STD*	597	2265	1757	1005	2224	1679	1125	646	1185	1451
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	4442	4777	5482	5737	5475	5241	6057	5343	5140	5299
	STD*	1662	450	1519	1108	350	487	575	697	1142	1029
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	5067	5618	6201	5572	5152	4907	5572	6423	5302	5535
	STD*	1761	1739	3700	1071	1663	1375	1252	4309	1518	2303

[a] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 1.

[b] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 0.

Table 23. The mean weights of calcium (average array 1), sodium (average array 2), magnesium (average array 3), potassium (average array 4), phosphorus (average array 5), and nitrogen (average array 6) in black gum leaf litter as a function of fertilizer treatment and time.

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 1											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*[a]	892	1027	933	876	1052	936	982	1018	913	959
	STD*	112	119	93	126	123	140	66	336	74	153
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	437	489	623	726	538	512	426	646	699	566
	STD*	37	63	248	279	142	147	38	368	95	206
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	399	558	649	525	442	733	502	568	551	547
	STD*	242	66	227	143	97	160	69	158	133	173
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	576	692	735	709	677	727	637	744	721	691
	STD*	273	259	238	236	299	227	259	348	181	260
AVERAGE ARRAY 2											
1	N	6	6	6	6	6	6	6	6	6	54
	MEAN*[b]	928	681	850	1013	843	985	802	1099	810	890
	STD*	185	101	91	407	135	244	142	386	220	252
2	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	349	332	540	502	376	356	364	468	446	415
	STD*	88	87	179	280	75	165	168	299	125	181
3	N	6	6	6	6	6	6	6	6	6	54
	MEAN*	320	462	711	470	392	595	415	511	431	478
	STD*	216	81	283	155	43	164	71	202	123	189
SUMS	N	18	18	18	18	18	18	18	18	18	162
	MEAN*	532	492	700	662	537	645	527	693	562	594
	STD*	331	171	229	380	239	324	237	412	236	297

Table 23. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 3											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*c	1731	1789	1757	1806	1633	1715	1870	1836	1657	1755
	STD*	233	232	200	333	421	226	286	508	377	312
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	375	303	290	393	473	301	353	415	413	368
	STD*	87	48	65	131	143	25	82	275	148	136
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	281	415	357	362	351	543	359	461	278	379
	STD*	179	92	134	98	153	144	47	44	78	134
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	796	836	801	854	819	853	861	904	782	834
	STD*	702	709	710	722	647	652	752	748	677	686
AVERAGE ARRAY 4											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*b	5020	4115	3731	5502	4117	4420	4588	4374	4155	4447
	STD*	1520	818	388	1880	685	1469	948	988	862	1176
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	2103	2220	2384	3259	2242	2402	1528	2687	2990	2424
	STD*	269	352	612	1245	378	664	333	1513	581	865
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	1756	2434	3354	2794	2428	3482	2031	3014	2403	2633
	STD*	1289	1306	1252	905	1227	894	597	2682	1079	1373
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	2960	2923	3156	3852	2929	3435	2715	3358	3183	3168
	STD*	1860	1223	978	1793	1173	1311	1517	1908	1105	1467

Table 23. (Continued)

		1	2	3	4	5	6	7	8	9	SUMS
AVERAGE ARRAY 5											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[c]	359	308	333	369	350	323	331	393	344	345
	STD*	48	29	56	51	77	64	47	76	62	59
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	366	384	1929	1859	271	509	193	1108	1048	852
	STD*	139	111	1793	1990	38	146	26	1022	439	1100
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	199	391	1175	825	206	1458	228	896	481	651
	STD*	125	107	1227	904	47	1155	34	879	203	785
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	308	361	1146	1018	276	763	251	799	624	616
	STD*	131	94	1356	1348	80	813	69	795	410	804
AVERAGE ARRAY 6											
	N	6	6	6	6	6	6	6	6	6	54
1	MEAN*[c]	6423	5736	6122	6325	6424	6277	6072	6171	6165	6191
	STD*	736	1056	760	850	1048	603	498	514	526	730
	N	6	6	6	6	6	6	6	6	6	54
2	MEAN*	6027	5932	5132	5358	5559	4588	3959	5414	5292	5251
	STD*	2930	3291	1031	434	1980	814	667	3511	1040	2016
	N	6	6	6	6	6	6	6	6	6	54
3	MEAN*	3438	4858	5157	4911	4243	6384	5493	5253	5608	5038
	STD*	2268	343	486	699	966	768	836	882	1490	1302
	N	18	18	18	18	18	18	18	18	18	162
SUMS	MEAN*	5296	5509	5470	5531	5409	5750	5175	5612	5688	5493
	STD*	2460	1944	881	883	1613	1092	1119	2025	1091	1525

[a] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 2.

[b] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 0.

[c] MULTIPLY MEANS AND STANDARD DEVIATIONS BY 10 TO THE 1.

APPENDIX E

Key to Appendix E

Columns 1 through 9 correspond to the following fertilizer treatments: (nitrogen/phosphorus) 0/0, 0/275, 0/550, 550/550, 550/0, 1100/550, 1100/0, 550/275, and 1100/275.

Table 24. Calcium concentration (μg/ml) of the soil solution in response to fertilizer treatment.

DATE	1	2	3	4	5	6	7	8	9
701221	7.28	6.40	12.22	9.97	8.93	11.72	9.80	18.82	5.64
701228	4.81	9.45	3.85	7.83	7.82	9.34	7.22	5.46	9.52
710104	4.67	4.76	8.34	7.22	6.32	9.87	7.67	4.37	4.12
710111	4.75	8.98	7.54	6.82	9.21	8.78	9.06	3.45	10.40
710118	4.60	6.40	7.40	6.56	7.31	7.43	6.53	3.51	4.76
710125	4.06	9.45	5.44	5.47	4.58	7.05	6.64	2.77	3.69
710215	4.33	4.76	6.24	6.44	8.48	7.21	7.08	3.78	6.07
710222	4.18	9.28	6.17	5.43	4.23	6.58	6.36	2.98	3.33
710322	7.11	32.58	493.00	118.00	9.72	121.54	14.76	158.11	192.71
710329	5.08	31.09	340.75	35.53	14.23	61.85	32.85	52.20	54.50
710405	5.22	26.10	204.38	30.20	15.66	65.50	27.75	28.25	28.75
710412	3.73	19.21	110.42	22.04	14.34	35.75	20.75	17.00	16.00
710426	4.77	16.83	67.45	18.49	20.63	27.75	13.00	10.48	12.75
710503	5.08	12.28	40.45	15.39	16.42	27.89	12.21	7.02	10.05
710514	5.31	14.80	47.79	34.47	27.76	69.08	17.58	9.31	16.77
710517	4.18	10.39	27.00	16.11	16.96	18.99	12.15	5.26	13.00
710531	11.88	10.17	22.41	36.99	40.54	56.16	46.26	8.95	5.22
710621	6.30	11.20	19.08	40.41	52.51	65.20	51.79	13.41	7.38
710712	5.77	10.35	19.70	12.90	10.67	18.88	30.07	6.42	10.10
710719	4.77	9.70	14.02	14.35	8.57	10.27	18.37	5.60	7.55
710726	4.90	10.72	13.82	8.40	16.00	10.02	14.60	6.13	5.85
710802	4.87	12.27	15.12	8.70	16.75	9.77	14.47	5.35	7.17
710809	4.15	10.12	12.52	7.82	8.37	7.82	8.07	4.52	4.05
710816	6.37	10.05	14.00	14.65	7.20	10.40	7.67	6.70	8.40
710920	5.65	12.32	13.42	9.82	5.97	10.35	6.60	7.32	6.50
710927	7.10	9.85	14.00	3.60	7.62	11.32	7.55	7.87	8.60
711011	5.53	12.16	13.39	7.57	7.06	8.65	6.37	6.03	7.59
711018	5.73	9.75	11.41	13.62	5.80	9.54	6.24	5.92	5.52
711115	10.00	17.80	8.15	10.30	11.87	10.75	16.75	10.37	23.20
711129	9.65	10.37	17.92	11.97	9.57	13.80	12.25	11.60	9.95
711206	6.90	12.00	12.95	8.20	5.55	8.27	7.88	7.62	6.35
711213	5.90	16.75	11.95	8.50	4.75	7.30	6.57	6.05	5.62
711220	6.40	8.40	11.38	7.92	5.88	8.85	7.45	7.27	6.15
711227	7.27	9.00	12.45	8.70	6.07	9.77	9.27	7.80	6.87
720103	6.36	10.32	9.72	6.42	4.89	7.96	6.46	6.27	5.26
720110	4.45	8.07	8.19	5.88	4.14	7.12	5.92	5.31	4.39
720117	5.46	5.79	7.59	5.25	4.09	5.71	5.41	5.14	4.47
720124	5.61	7.02	8.25	6.30	4.53	7.99	7.29	6.24	5.13
720207	5.04	6.84	8.40	3.57	4.41	7.83	6.99	5.95	5.25
720214	5.17	12.19	8.05	5.82	4.75	8.10	6.73	6.21	5.09
720221	5.43	10.98	9.03	6.46	5.02	8.23	7.56	6.33	5.64
720228	5.28	12.22	9.06	6.57	4.96	8.07	7.87	6.45	5.97
720306	4.22	7.85	7.35	5.35	4.22	7.15	5.55	5.02	4.47

Table 25. Sodium concentration (μg/ml) of the soil solution in response to fertilizer treatment.

DATE	1	2	3	4	5	6	7	8	9
701221	1.72	1.58	2.42	1.64	1.88	1.69	1.61	2.01	1.71
701228	0.79	2.38	0.90	0.84	0.88	0.86	0.79	0.80	0.90
710104	0.65	0.68	1.57	0.70	0.76	1.29	0.63	0.68	0.71
710111	1.26	1.27	1.26	1.29	1.22	1.27	1.07	1.14	1.18
710118	1.38	1.58	1.44	1.38	1.34	1.32	1.19	1.26	1.30
710125	1.23	2.38	1.22	1.25	1.38	1.18	1.27	1.27	1.35
710215	1.21	0.68	1.38	1.31	1.54	1.26	1.18	1.20	1.30
710222	1.16	1.45	1.26	1.17	1.27	1.18	1.15	1.19	1.19
710322	1.66	2.51	9.24	4.80	1.64	5.32	1.98	4.96	6.70
710329	1.11	2.65	11.71	7.70	1.81	7.14	2.29	5.66	5.32
710405	1.31	2.78	8.80	2.37	2.16	2.71	1.47	2.54	2.77
710412	1.02	2.33	5.64	4.39	1.66	2.86	1.19	1.78	2.15
710426	0.94	1.88	1.85	1.52	1.68	2.01	0.93	1.68	1.54
710503	0.99	1.50	2.38	2.19	1.26	1.70	1.01	1.34	1.79
710514	1.13	1.68	2.49	2.15	1.15	2.22	1.10	1.52	1.75
710517	0.89	1.26	1.62	1.69	0.97	1.35	0.90	1.11	1.28
710531	1.06	1.26	1.62	1.71	1.45	1.69	1.14	1.26	2.22
710621	0.48	1.49	1.17	1.98	1.24	0.71	1.17	1.06	2.33
710712	0.81	0.95	0.63	1.87	0.54	0.55	1.10	0.95	0.65
710719	0.75	1.03	1.22	1.12	0.93	1.06	0.91	0.87	1.03
710726	0.78	0.86	0.93	1.38	0.76	0.79	0.76	0.81	0.93
710802	0.79	0.88	0.94	1.14	0.81	0.99	0.69	0.94	0.84
710809	0.75	0.90	0.94	1.27	0.79	0.99	0.69	0.92	0.92
710816	0.72	0.83	1.27	1.13	0.89	1.19	1.03	0.98	1.02
710920	0.97	1.13	1.17	3.03	0.97	1.45	0.96	1.15	1.17
710927	0.93	1.09	1.94	1.85	2.11	1.59	1.12	1.46	1.33
711011	0.97	1.27	1.26	1.74	1.11	1.33	1.15	1.19	2.22
711018	1.13	1.30	1.89	2.76	1.88	2.85	1.39	1.50	1.17
711115	1.30	1.27	1.22	1.16	2.14	1.40	2.25	1.40	2.06
711129	0.93	0.68	1.32	1.83	1.37	1.84	1.36	1.45	1.90
711206	0.94	1.09	1.10	1.50	0.93	1.08	1.84	1.10	1.14
711213	1.42	1.74	1.42	1.46	1.55	1.52	1.52	1.51	1.52
711220	1.08	1.28	1.41	1.58	1.52	1.47	1.48	1.46	1.53
711227	0.73	1.40	1.64	1.77	1.60	1.57	0.98	1.68	1.65
720103	2.08	1.36	1.34	1.55	1.37	1.59	1.42	1.44	1.51
720110	1.42	1.26	1.21	1.44	1.29	1.45	1.40	1.35	1.32
720117	1.32	1.17	1.57	1.47	1.48	1.44	1.27	1.35	1.40
720124	1.66	1.50	1.56	2.35	1.53	1.53	2.45	1.57	1.58
720207	0.96	1.10	1.03	1.39	1.07	1.18	1.00	1.07	0.98
720214	1.11	1.20	1.16	1.28	1.24	1.23	1.15	1.16	1.18
720221	1.09	1.84	1.11	1.29	1.16	1.24	1.21	1.05	1.13
720228	1.03	1.48	1.15	1.26	1.11	1.17	1.13	1.24	1.33
720306	1.34	1.38	1.34	1.40	1.25	1.40	1.29	1.37	1.32

Table 26. Magnesium concentration (μg/ml) of the soil solution in response to fertilizer treatment.

DATE	1	2	3	4	5	6	7	8	9
701221	1.90	1.76	4.29	3.55	3.45	4.31	3.05	8.33	1.98
701228	1.14	2.98	2.70	2.70	2.77	3.35	2.19	1.88	3.39
710104	1.26	1.32	2.47	2.53	2.16	3.29	2.39	1.42	1.52
710111	1.23	3.18	2.33	2.35	3.21	3.14	2.32	1.05	3.16
710118	1.17	1.76	2.46	2.17	2.22	2.75	1.97	1.06	1.74
710125	1.01	2.98	1.92	1.98	1.50	2.56	1.96	0.86	1.26
710215	1.04	1.32	2.17	2.24	3.63	2.70	2.13	0.91	2.31
710222	0.96	3.49	2.07	1.83	1.80	2.36	1.86	0.82	1.22
710322	1.28	13.14	64.38	48.75	3.96	42.88	4.40	30.77	35.00
710329	1.12	12.79	44.97	5.46	7.09	19.50	8.25	12.98	4.63
710405	1.24	11.85	25.45	6.67	6.91	11.63	6.75	5.88	6.38
710412	1.04	8.00	13.02	7.02	5.17	8.00	4.00	3.75	3.38
710426	1.62	6.91	7.72	7.50	6.80	7.50	2.52	2.52	2.75
710503	1.12	4.94	4.78	6.32	5.84	9.60	1.78	1.24	1.92
710514	1.12	5.82	5.70	9.95	11.45	27.75	4.46	1.98	4.30
710517	0.84	3.86	3.38	4.28	6.44	5.50	2.66	1.08	3.44
710531	2.88	3.56	2.72	8.37	13.13	17.03	16.70	2.74	0.64
710621	1.18	3.95	2.10	9.44	14.00	21.55	12.44	2.90	0.92
710712	1.22	3.50	2.52	2.20	2.50	5.32	6.92	1.35	1.77
710719	0.85	3.05	1.80	2.70	2.00	2.57	3.77	1.32	1.27
710726	0.90	3.12	1.62	1.72	3.60	2.62	3.27	1.22	0.97
710802	1.07	3.77	1.92	1.95	3.40	2.90	3.32	1.38	1.22
710809	0.77	3.22	1.77	1.75	1.90	2.57	2.02	1.35	1.00
710816	1.70	2.90	2.22	3.15	2.07	3.57	2.17	2.22	1.90
710920	1.40	4.05	2.22	2.05	1.40	6.21	1.72	2.35	1.35
710927	1.75	2.95	2.17	2.59	1.75	3.70	2.15	2.20	1.70
711011	1.29	3.87	2.28	1.84	1.60	3.07	1.72	1.80	1.66
711018	1.47	4.11	1.89	3.12	1.65	3.10	1.17	1.83	1.11
711115	1.95	6.00	2.30	2.55	3.55	3.55	4.20	3.02	4.15
711129	3.52	4.82	3.07	4.67	2.90	5.67	2.65	3.62	2.17
711206	1.95	4.00	2.20	2.50	1.70	3.57	2.52	2.25	1.32
711213	1.67	4.65	1.97	1.95	1.65	2.32	1.87	1.72	1.10
711220	1.40	2.35	1.87	2.15	1.60	3.00	2.05	1.77	1.25
711227	1.02	2.50	2.05	2.37	1.75	3.45	2.60	1.97	1.45
720103	1.44	2.89	1.63	1.90	1.33	2.88	1.83	1.62	1.11
720110	0.96	2.19	1.33	1.63	1.17	2.53	1.63	1.30	0.94
720117	1.63	1.44	1.26	1.45	1.14	1.80	1.45	1.18	0.94
720124	1.29	1.77	1.35	1.63	1.30	2.82	1.75	1.56	1.11
720207	1.11	1.65	1.33	1.35	1.24	2.71	1.96	1.41	1.14
720214	0.78	1.05	0.43	1.07	0.83	1.06	1.04	0.51	0.67
720221	1.15	2.98	1.42	1.80	1.38	3.04	2.04	1.62	1.29
720228	1.18	3.28	1.47	1.81	1.35	2.89	1.75	1.63	1.24
720306	0.55	2.22	1.27	1.52	1.20	2.75	1.52	1.32	1.00

Table 27. Potassium concentration (μg/ml) of the soil solution in response to fertilizer treatment.

DATE	1	2	3	4	5	6	7	8	9
701221	9.84	9.72	5.26	8.43	9.25	10.02	8.13	10.22	14.34
701228	8.52	15.21	6.35	8.12	8.57	8.97	7.93	8.56	7.60
710104	7.62	7.30	8.30	8.15	10.70	11.92	7.44	8.20	10.72
710111	11.21	10.37	8.83	10.03	9.97	10.00	9.27	12.42	12.56
710118	9.37	9.72	8.90	9.88	9.78	11.38	8.96	10.52	12.32
710125	6.30	15.21	7.06	7.32	7.40	6.54	6.19	7.64	8.94
710215	4.98	7.30	6.78	5.91	5.30	5.69	4.61	5.97	4.96
710222	4.75	9.92	4.77	5.69	4.16	5.61	4.43	5.88	4.21
710322	3.95	3.02	17.67	9.90	3.52	8.25	5.45	12.72	19.47
710329	9.90	11.20	22.12	41.63	18.57	39.21	37.05	21.95	42.35
710405	6.40	8.67	15.12	33.17	19.92	22.55	28.92	18.25	32.22
710412	3.15	8.50	10.72	17.22	16.10	17.65	9.42	12.27	20.00
710426	2.80	4.72	6.17	12.10	12.60	14.35	8.50	6.90	13.50
710503	3.57	4.42	4.95	8.20	10.42	10.17	6.10	4.77	9.57
710514	3.00	4.97	4.42	8.00	13.70	13.17	8.45	6.42	12.87
710517	2.10	4.02	3.17	4.62	10.00	5.57	5.50	3.67	6.97
710531	10.00	3.65	2.10	3.60	12.02	6.70	4.35	4.10	3.90
710621	3.20	3.77	1.20	2.85	8.42	4.85	9.85	1.47	4.65
710712	3.39	3.22	1.65	1.62	3.64	2.15	5.85	1.60	3.59
710719	2.61	3.37	1.14	2.07	2.58	1.58	3.97	1.49	2.29
710726	2.51	3.66	1.15	1.26	2.44	1.54	3.60	1.25	1.82
710802	2.09	3.93	0.97	0.94	1.74	1.35	2.84	1.10	1.77
710809	1.49	3.48	0.80	0.78	0.90	1.28	1.77	0.93	1.39
710816	2.42	0.85	1.03	1.56	1.71	1.32	2.34	1.44	3.03
710920	3.10	4.79	1.60	1.93	3.62	1.82	3.91	2.31	3.98
710927	3.58	1.18	1.69	0.66	3.18	1.44	4.46	2.45	4.62
711011	4.38	4.89	1.33	1.20	4.47	1.64	4.50	2.34	2.90
711018	3.62	5.07	1.31	1.92	3.75	1.58	3.35	2.28	3.71
711115	6.63	4.52	5.42	6.15	3.86	9.09	1.76	3.99	3.64
711129	6.35	4.98	2.93	2.24	7.51	2.30	13.15	7.47	5.04
711206	8.30	6.70	3.30	2.60	5.70	5.45	8.97	7.25	6.45
711213	8.55	14.90	3.60	5.85	3.30	4.90	8.87	7.20	7.00
711220	7.62	2.75	4.65	2.77	6.85	6.97	7.90	8.17	7.57
711227	3.80	3.15	5.07	2.82	6.22	6.80	7.27	8.30	7.55
720103	6.47	6.96	3.92	3.03	4.59	5.73	5.01	6.32	5.47
720110	4.21	5.66	3.30	2.62	3.51	4.94	3.76	5.14	4.44
720117	4.12	2.16	3.66	2.60	3.44	4.80	3.05	4.49	4.52
720124	4.37	2.28	3.33	2.69	3.46	4.99	3.33	5.18	4.78
720207	3.52	2.21	3.32	1.42	3.00	4.61	2.72	4.62	6.12
720214	3.60	6.42	3.04	2.48	2.92	4.39	2.66	4.36	4.29
720221	3.67	3.77	3.07	2.66	2.89	4.34	2.74	4.35	6.04
720228	3.59	6.85	2.84	2.97	2.97	4.38	2.69	4.09	4.32
720306	3.18	5.52	2.57	2.96	2.66	4.22	2.39	3.71	3.94

Table 28. Phosphorus concentration (μg/ml) of the soil solution in response to fertilizer treatment.

DATE	1	2	3	4	5	6	7	8	9
701221	0.03	0.05	0.02	0.03	0.04	0.53	0.02	0.02	0.05
701228	0.03	0.03	0.03	0.05	0.04	0.26	0.04	0.03	0.06
710104	0.03	0.07	0.02	0.04	0.08	0.28	0.02	0.03	0.06
710111	0.01	0.02	0.02	0.02	0.02	0.67	0.01	0.02	0.03
710118	0.01	0.05	0.03	0.02	0.02	0.90	0.01	0.02	0.03
710125	0.02	0.03	0.03	0.02	0.03	0.35	0.01	0.02	0.02
710215	0.04	0.07	0.04	0.05	0.05	0.23	0.03	0.03	0.03
710222	0.02	0.01	0.05	0.03	0.04	0.06	0.02	0.04	0.02
710322	0.35	20.65	852.10	236.40	0.86	178.75	0.89	274.65	330.35
710329	45.40	21.05	459.35	261.65	0.44	109.95	1.12	114.05	139.35
710405	0.20	19.65	263.95	213.60	0.48	50.45	1.40	69.10	79.55
710412	0.41	0.14	97.82	140.95	0.49	103.85	0.48	18.53	32.11
710426	0.02	173.60	76.90	97.80	0.22	75.90	1.42	31.15	39.00
710503	0.01	5.44	42.36	58.48	0.14	53.07	0.89	17.68	22.58
710514	0.02	6.70	50.08	51.33	0.08	18.74	0.66	21.45	19.19
710517	0.02	6.01	31.70	36.68	0.20	34.08	0.31	16.38	14.83
710531	0.14	3.93	24.65	13.11	0.04	14.68	0.07	7.76	13.61
710621	0.01	2.75	15.14	17.37	0.01	6.97	0.02	4.05	5.81
710712	0.01	2.63	13.67	8.19	0.02	6.15	0.03	2.71	2.19
710719	0.02	1.92	8.10	12.78	0.01	2.59	0.02	2.76	1.82
710726	0.01	1.65	11.11	8.93	0.01	5.81	0.01	2.94	1.96
710802	0.01	1.73	12.11	11.04	0.01	6.24	0.02	2.99	2.37
710809	0.04	1.82	5.60	8.05	0.02	5.50	0.02	2.72	1.93
710816	0.01	1.60	7.94	8.55	0.01	3.16	0.03	1.62	1.56
710920	0.04	1.33	7.72	4.12	0.06	4.51	0.05	2.26	2.14
710927	0.01	1.17	6.75	2.65	0.02	3.97	0.02	2.08	1.79
711011	0.01	0.99	6.42	5.39	0.02	3.67	0.02	1.87	1.10
711018	0.01	0.93	5.75	8.10	0.03	4.10	0.01	1.48	1.60
711115	0.02	2.16	0.90	0.03	0.46	0.04	1.42	2.04	2.80
711129	0.00	0.0	4.42	2.85	0.02	2.04	0.04	1.49	0.84
711206	0.01	0.73	4.72	4.25	0.01	2.51	0.02	1.53	1.13
711213	1.47	0.79	5.46	2.98	1.79	1.51	0.02	1.59	1.36
711220	0.04	0.97	5.21	4.48	0.03	2.76	0.03	1.57	1.40
711227	0.03	0.94	4.96	4.56	0.02	2.74	0.01	1.55	1.32
720103	0.03	0.76	4.62	3.80	0.02	2.65	0.02	1.45	1.23
720110	0.02	0.74	4.12	4.02	0.01	2.65	0.02	1.33	0.51
720117	1.04	0.92	3.69	3.55	0.02	1.76	0.02	0.75	1.07
720124	0.03	0.80	4.75	3.18	0.02	1.97	0.02	1.09	1.03
720207	0.10	0.79	3.28	2.50	0.03	2.07	0.10	1.09	1.15
720214	0.01	0.56	1.42	1.75	0.01	2.20	0.01	1.09	0.92
720221	0.01	0.51	3.23	3.34	0.01	2.14	0.01	1.03	0.98
720228	0.01	0.54	1.40	1.59	0.01	2.08	0.01	0.98	0.85
720306	0.01	0.61	3.57	3.06	0.01	2.07	0.01	0.96	0.92

Table 29. Ammonium concentration (μg/ml) of the soil solution in response to fertilizer treatment.

DATE	1	2	3	4	5	6	7	8	9
701221	0.46	0.17	0.75	0.20	0.44	0.22	0.23	0.23	0.43
701228	0.42	0.63	0.60	0.24	0.39	0.48	0.37	0.26	0.52
710104	0.36	0.24	0.37	0.23	0.46	0.40	0.24	0.23	0.38
710111	0.77	0.77	0.72	0.56	0.54	1.57	0.62	0.70	0.96
710118	0.77	0.17	0.99	0.90	0.91	2.19	0.71	0.70	0.95
710125	0.52	0.63	0.46	0.40	0.35	0.38	0.32	0.42	0.55
710215	0.33	0.24	0.20	0.13	0.23	0.07	0.08	0.14	0.14
710222	1.13	0.59	0.18	0.07	0.07	0.93	0.03	0.06	0.17
710322	1.47	1.36	2.41	29.03	18.66	24.66	52.82	37.22	127.88
710329	2.05	2.62	4.90	413.93	166.51	380.92	426.17	147.96	651.05
710405	1.56	2.50	3.35	469.73	118.61	450.40	309.68	162.57	311.24
710412	1.37	4.30	4.18	190.62	97.66	304.92	119.98	107.41	243.76
710426	1.11	1.80	2.25	112.22	76.83	229.43	148.56	73.13	161.62
710503	1.21	1.35	1.85	72.35	59.24	136.08	95.03	48.16	96.10
710514	1.69	1.80	1.69	59.42	65.18	108.58	100.35	58.46	101.08
710517	1.50	1.48	2.20	64.68	64.00	59.36	77.33	47.09	96.20
710531	9.92	3.00	1.83	15.87	41.16	38.25	23.63	29.34	61.60
710621	1.55	1.49	1.71	16.24	21.95	18.48	52.02	13.72	48.72
710712	1.69	1.61	1.66	17.65	14.39	14.28	19.93	13.72	19.93
710719	1.44	1.62	2.95	11.09	15.34	23.24	14.61	12.77	14.56
710726	2.00	2.17	2.06	17.41	11.76	14.16	15.12	12.37	11.70
710802	1.89	1.87	2.01	8.34	7.44	8.88	8.48	7.61	6.80
710809	3.20	3.17	2.88	13.72	10.78	12.90	11.28	14.11	9.57
710816	3.48	2.74	2.21	13.33	12.51	14.17	13.77	12.63	12.88
710920	3.93	2.99	8.52	14.16	12.88	11.45	12.37	13.75	12.60
710927	3.93	3.35	3.99	8.73	18.22	19.29	19.09	18.79	18.70
711011	1.46	1.70	2.47	8.29	8.85	8.68	7.75	5.76	9.15
711018	1.61	1.57	13.60	12.71	13.97	7.76	17.42	7.65	12.77
711115	3.11	3.01	3.53	1.48	2.35	2.92	2.99	3.19	2.09
711129	1.66	1.84	1.53	0.64	1.19	1.65	1.47	1.42	1.59
711206	1.66	2.09	1.57	2.00	2.38	1.42	1.38	1.35	1.26
711213	1.84	2.28	1.98	1.41	1.64	1.66	1.70	1.04	1.77
711220	1.58	1.33	1.59	2.07	1.94	1.56	1.71	1.76	1.84
711227	2.25	1.34	1.37	1.52	1.59	2.60	1.66	2.12	1.55
720103	1.82	2.05	1.55	4.35	1.20	1.76	4.94	1.53	1.58
720110	1.42	1.61	1.67	1.91	1.45	1.91	1.41	1.88	1.35
720117	1.40	2.49	1.93	1.44	1.63	1.47	1.36	1.84	2.32
720124	1.94	1.87	2.06	2.04	1.88	1.88	2.19	1.92	2.14
720207	1.29	2.27	2.08	1.11	1.60	1.10	1.02	1.28	1.93
720214	1.12	1.36	1.03	1.45	1.42	1.04	1.54	1.21	6.12
720221	1.70	1.40	1.67	1.48	1.30	1.72	1.63	1.58	1.47
720228	1.42	1.98	1.77	1.68	1.84	1.67	2.11	1.89	2.17
720306	1.28	1.32	1.28	1.29	1.26	1.34	1.31	1.23	1.52

Table 30. Nitrogen concentration (μg/ml) of the soil solution in response to fertilizer treatment.

DATE	1	2	3	4	5	6	7	8	9
701221	0.82	0.35	1.81	0.33	1.07	0.75	0.39	0.52	0.51
701228	1.00	0.87	0.76	0.66	0.69	0.74	0.68	0.88	0.85
710104	0.57	0.55	0.79	0.71	0.80	0.69	0.61	1.08	0.75
710111	2.70	2.38	2.36	1.65	1.59	2.24	2.05	2.59	3.88
710118	3.72	0.35	3.02	3.14	3.17	3.09	3.38	2.66	3.10
710125	1.27	0.87	1.18	0.96	0.91	0.73	0.78	0.76	1.45
710215	1.19	0.55	0.34	0.23	0.33	0.30	0.20	0.27	0.20
710222	1.39	2.00	0.99	0.80	0.85	1.00	0.71	0.85	0.70
710322	4.42	9.29	6.17	1177.12	730.80	2133.04	2292.64	1696.80	4714.64
710329	2.48	4.24	7.14	907.20	770.00	1697.36	1532.16	661.36	2284.80
710405	3.50	3.03	7.17	417.20	286.72	636.16	582.96	364.56	614.88
710412	1.93	3.38	4.33	288.40	192.08	406.56	325.36	203.84	356.80
710426	2.09	3.36	4.42	376.32	242.48	348.32	252.00	223.44	261.52
710503	1.69	2.12	3.73	211.12	184.80	260.40	228.48	170.80	200.48
710514	1.57	2.51	2.95	133.84	173.04	286.72	204.40	171.92	215.04
710517	2.19	2.54	2.44	201.60	224.56	175.28	208.88	217.84	227.92
710531	2.67	3.63	2.94	183.68	202.72	246.96	143.36	167.44	257.60
710621	2.44	2.85	2.63	140.00	166.32	155.12	124.88	146.72	216.16
710712	2.66	2.96	3.05	189.84	147.28	175.28	161.28	189.28	116.48
710719	17.31	8.80	2.32	170.24	179.76	154.00	164.08	175.28	175.28
710726	2.96	3.27	2.70	21.56	20.44	22.12	21.67	20.10	22.12
710802	4.95	5.51	4.87	37.30	33.04	39.81	27.44	32.42	26.09
710809	3.35	3.92	3.68	26.09	23.24	23.29	22.68	18.98	21.34
710816	24.64	4.04	4.85	33.04	36.79	27.77	132.94	36.51	31.70
710920	3.70	4.43	4.45	29.34	35.39	31.13	32.31	30.24	35.73
710927	5.35	5.26	6.14	18.25	43.23	45.58	46.48	43.57	40.99
711011	1.97	2.04	2.05	36.73	24.19	19.99	21.89	17.30	27.72
711018	2.61	1.92	3.77	27.78	26.37	16.11	24.86	23.80	26.54
711115	3.48	5.48	5.15	2.92	6.75	6.58	6.30	5.02	5.36
711129	3.54	4.58	1.64	3.16	2.33	2.15	2.91	1.90	2.61
711206	1.62	2.06	1.84	1.94	1.83	2.05	6.43	2.31	2.09
711213	1.72	1.97	1.75	1.86	1.99	1.82	2.82	1.12	2.24
711220	2.45	1.95	2.09	2.62	2.57	2.83	3.17	2.57	3.05
711227	2.65	2.49	2.89	2.70	2.62	2.73	3.61	2.53	3.10
720103	2.16	2.98	2.24	3.30	2.16	2.55	2.68	2.29	2.48
720110	2.07	2.27	2.06	2.98	2.56	1.93	2.47	2.09	2.38
720117	1.88	3.83	1.78	4.06	1.77	1.87	2.50	2.59	2.31
720124	3.08	2.49	3.42	3.38	3.01	3.41	3.29	2.97	3.25
720207	1.65	2.35	2.47	1.49	2.23	1.87	2.26	1.71	2.72
720214	3.25	2.06	1.62	2.11	1.69	2.08	2.11	1.73	1.94
720221	1.94	2.53	1.84	2.10	1.83	2.64	2.41	2.28	2.68
720228	1.73	2.87	1.87	2.17	1.92	1.96	2.54	2.30	2.42
720306	1.95	1.86	1.80	2.60	1.87	1.72	1.95	1.74	2.12

ORNL-4893
UC-48 — Biology and Medicine

INTERNAL DISTRIBUTION

1. Biology Library
2-4. Central Research Library
5. ORNL — Y-12 Technical Library
Document Reference Section
6-40. Laboratory Records Department
41. Laboratory Records, ORNL R.C.
42. ORNL Patent Office
43. J. A. Auxier
44-144. S. I. Auerbach
145. R. L. Burgess
146. F. L. Culler
147. R. C. Dahlman
148. J. W. Elwood
149. N. Ferguson
150. C. W. Francis
151. F. G. Goff
152. W. F. Harris
153. G. S. Henderson
154. R. F. Hibbs
155-175. J. M. Kelly
176. D. J. Nelson
177. J. S. Olson
178. D. E. Reichle
179. W. A. Thomas
180. J. Totter
181. G. U. Ulrikson
182. A. M. Weinberg
183. M. Witkamp

EXTERNAL DISTRIBUTION

184. C. L. Osterberg, Division of Biomedical and Environmental Research, USAEC, Washington, D.C. 20545
185. W. S. Osburn, Division of Biomedical and Environmental Research, USAEC, Washington, D.C. 20545
186. Jeff Swinebroad, Ecological Sciences Branch, Division of Biomedical and Environmental Research, USAEC, Washington, D.C. 20545
187. J. N. Wolfe, Division of Biomedical and Environmental Research, USAEC, Washington, D.C. 20545
188. Hal Hollister, Division of Biomedical and Environmental Research, USAEC, Washington, D.C. 20545
189. John Kirby-Smith, Biological Sciences Branch, Division of Biomedical and Environmental Research, USAEC, Washington, D.C. 20545
190. J. L. Liverman, Division of Biomedical and Environmental Research, USAEC, Washington, D.C. 20545
191. Robert Rabson, Biological Sciences Branch, Division of Biomedical and Environmental Research, USAEC, Washington, D.C. 20545
192. R. E. Benson, Research and Technical Support Division, ORO, USAEC, Oak Ridge, Tennessee 37830
193. C. C. Amundensen, Graduate Program in Ecology, University of Tennessee, Knoxville, Tennessee 37919
194. J. W. Barrett, Forestry Department, University of Tennessee, Knoxville, Tennessee 37919
195. Kermit Cromack, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon 97331
196. J. W. Curlin, Environmental Policy Division, Congressional Research Service, Library of Congress, Washington, D.C. 20540
197. S. Gessel, School of Forestry, University of Washington, Seattle, Washington 98105

198. J. H. Hughes, Weyerhaeuser Corporation, P. O. Box 1391, New Bern, North Carolina 28560
199. K. R. Knoerr, School of Forestry, Duke University, Durham, North Carolina 27706
200. G. C. Kyker, University Programs Office, Oak Ridge Associated Universities, Oak Ridge, Tennessee 37830
201. G. M. Lessman, Department of Plant and Soil Science, University of Tennessee, Knoxville, Tennessee 37919
202. Gene E. Likens, Department of Ecology, Cornell University, Ithaca, New York 14850
203. H.A.I. Madgwick, Department of Forestry, Virginia Polytechnic Institute, Blacksburg, Virginia 24061
204. C. D. Monk, Department of Botany, University of Georgia, Athens, Georgia 30601
205. C. E. Murphy, School of Forestry, Duke University, Durham, North Carolina 27706
206. W. S. Overton, School of Forestry, Oregon State University, Corvallis, Oregon 97331
207. Goran Petersson, Department of Plant Ecology, Lunds Universitet, Ostra Vallgatan 14-18, Lund, SWEDEN
208. Thomas Ripley, Division of Forestry, Fisheries and Wildlife, Tennessee Valley Authority, Norris, Tennessee 37828
209. Thomas Rosswall, Secretary, Swedish IBP Committee, Wenner-Gren Center, Sveavagen 166, 8 TR, S-113 46, Stockholm, SWEDEN
210. B. R. Strain, Department of Botany, Duke University, Durham, North Carolina 27706
211. Wayne T. Swank, Coweeta Hydrolic Laboratory, U.S. Forest Service, Franklin, North Carolina 25734
212. J. A. Swartout, Union Carbide Corporation, New York 10017
213. C. O. Tamm, Department of Plant Ecology and Forest Soils, Royal College of Forestry, Stockholm, SWEDEN
214. Henry A. Wright, Department of Range and Wildlife Management, Texas Tech University, Lubbock, Texas 79409
215. Research and Technical Support Division, AEC, ORO
216. Patent Office, AEC, ORO

217-405. Given distribution as shown in TID-4500 under Biology and Medicine category (25 copies — NTIS)

☆U.S. GOVERNMENT PRINTING OFFICE: 1973-747-302/46

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
NUCLEAR DIVISION

UNION CARBIDE

POST OFFICE BOX X
OAK RIDGE, TENNESSEE 37830

SPECIAL 4TH CLASS RATE BOOKS

If a change of address is needed, indicate the change, include the zip code, and identify the document; tear off this cover and return it to the above address.